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boiler; it automatically relieves the steam pressure when the pressure rises above that for which the valve is set.

3. Classification of Steam Boilers.—Steam boilers may be classified according to their form, construction, and use. Thus, according to their form, boilers are *horizontal* or *vertical;* according to their construction, they are *shell, flue, sectional, fire-tube,* or *water-tube boilers;* according to the different conditions under which they are used, they are designated as *stationary, locomotive,* or *marine boilers.*

A shell, or cylindrical, boiler is one consisting of a plain cylinder closed at both ends. A sectional boiler is one made up of a number of cast-iron sections that are assembled and bolted together. This type of boiler is chiefly employed for low-pressure heating purposes. A flue boiler is made up of a cylindrical shell having one or more large flues, or pipes, 6 inches or more in diameter, surrounded by water and so arranged that the hot gases must pass through the flues. A fire-tube boiler resembles a flue boiler in principle, but in it a large number of tubes take the place of the flues. The tubes are generally 5½ inches or less in diameter. The hot gases pass through these tubes just as they pass through the larger flues of a flue boiler. A water-tube boiler consists of a number of tubes connected to drums and so arranged that water circulates within them while the heating is done by the hot gases surrounding them. The main features of different types of boilers are frequently combined, giving rise to a large number of special forms.

STATIONARY BOILERS

SHELL, FLUE, TUBULAR, AND WATER-TUBE TYPES

4. Plain Cylindrical, or Shell, Boiler.—The plain cylindrical, or shell, boiler is now rarely used; but because it is of simple construction, it will be described, to bring out certain general features that are common to many boilers. It is not economical on account of its small heating surface. Its advan-

iron or steel plates riveted together, the girth seams having a single row of rivets and the longitudinal seams a double row of rivets. The shells of boilers of this type are usually from 30 inches to 40 inches in diameter, and from 20 feet to 40 feet in length, although in some cases the length has been made as great as 70 feet. The *heads,* or ends, of the cylinder are either hemispherical or flat. The former are more generally used, as they are stronger than flat heads and require no bracing. The manner of suspending the shell is clearly shown. The boiler is

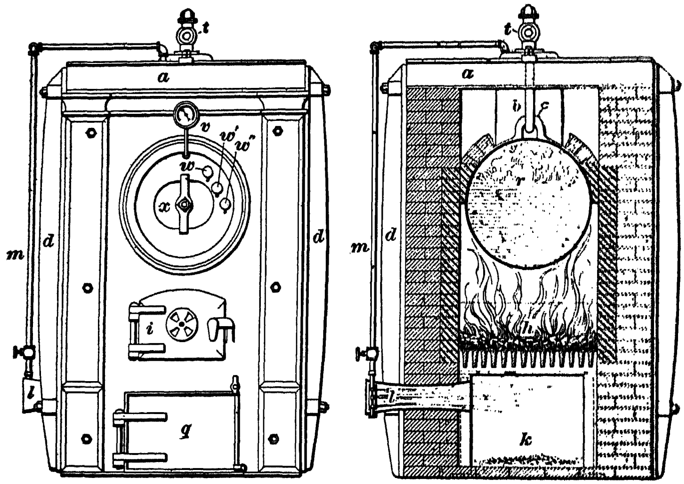


FIG. 2

supported and enclosed by side walls of brick, known as the *boiler setting.* The channel beams *a* are laid across the brick side walls, and the boiler is suspended from the beams by means of the hooks *b* and eyes *c,* the latter being riveted to the shell.

6. The side walls are supported and prevented from buckling by the *binders,* or *buckstaves, d,* Fig. 2, bolted together at the top and at the bottom. The buckstaves are cast-iron bars of **T** section. The eyes *c* are placed about one-fourth of the length of the shell from each end. This method of suspension allows the shell to expand and contract freely when heated or cooled.

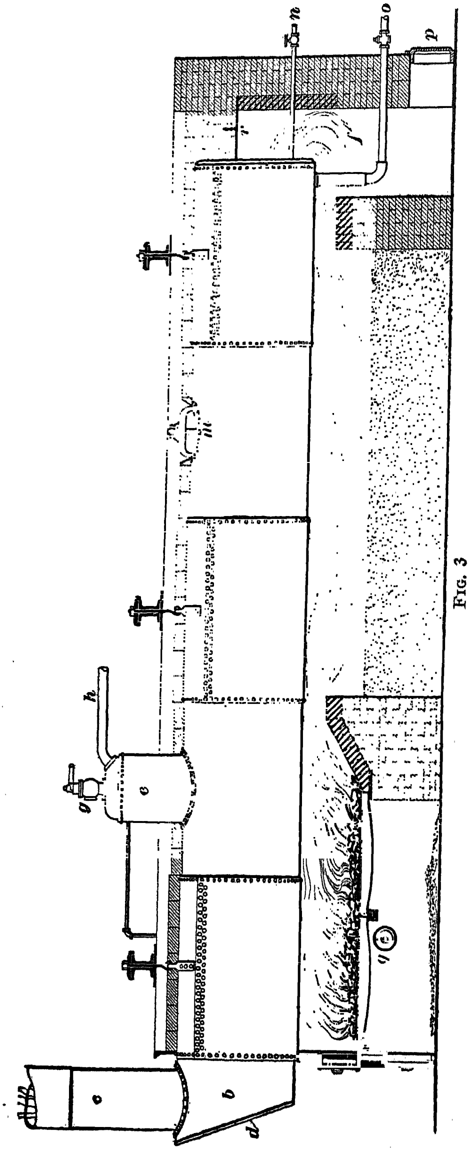


Fig. 3

The brickwork covers the upper portion of the boiler shell in such a manner as to prevent the hot gases from coming into contact with the shell above the water-line *r*, Fig. 2. The top of the shell is covered by brickwork or some other non-conducting material to prevent radiation of heat. Water is forced into the boiler through the feedpipe *s*, Fig. 1, from a pump or an injector. When in operation the water stands at about the level *r*, the space above being occupied by the steam.

8. The safety valve is shown at *t*, Fig. 1. It opens automatically when the pressure reaches the point for which the valve is set, and allows enough steam to escape so that the pressure will not rise above the desired point. Steam is taken from the boiler

front of the smokebox is provided with a door *d*. The boiler shell is also provided with the *dome e*, which forms a chamber where steam may collect and free itself from its entrained water before passing to the engine. The manner of supporting the shell and the construction of the furnace and bridge walls are the same as for the plain cylindrical boiler. The hot gases, however, pass over the bridge walls to the chamber *f*, and then back through the flues *a* into the smokebox *b* and out of the stack *c*. It is plain that the heating surface is greater than that of the plain cylindrical boiler by the cylindrical surfaces of the flues *a*.

The boiler has a cast-iron front, to which the furnace door and ash-pit doors are attached. The safety valve *g* is attached to the top of the dome. The steam pipe *h* leads from the dome to the engine. The steam gauge *i* and gauge-cocks are placed on a column *j* that communicates with the interior of the shell through the pipes *k* and *l*, the former entering the steam space and the latter the water space. The manhole *m* is placed on top of the shell instead of in the head. The feedpipe is shown at *n*, and the blow-off pipe at *o*, both passing through the rear wall. Access is given to the rear end of the shell and to the pipes *n* and *o* through the door *p*. This form of boiler may be provided with a blower, as shown at *q*. The setting is built and supported in about the same manner as that shown in Fig. 1. The cast-iron *flue plate r* rests on the side and rear walls and supports the brickwork above it.

10. Horizontal Return-Tubular Boiler.—The return-tubular boiler is so largely used in the United States that it is regarded as the standard American fire-tube boiler. When properly constructed and operated it is very efficient. It is a modification of the flue boiler, the flues being replaced by tubes that are smaller and more numerous than the flues, usually ranging in size from 2½ to 4 inches in diameter. The greater part of the heating surface is provided by the tubes. Less space is required for the installation of this type, as compared with the shell boiler or the flue boiler of equal steam-generating capacity.

11. Firebrick is used for all parts of the wall exposed to the fire or heated gases. The fittings are not shown in Fig. 5. The safety valve is placed on top of the dome, and the pressure gauge and gauge-cocks are placed on the front. The manhole may be either in one of the heads or on top of the shell, although sometimes manholes are provided in both ends and in the top of the shell. The feedpipe may enter the front head, while the blow-off pipe *i* is placed at the bottom of the shell, at the rear end. Access is given to the rear end of the boiler through a clean-out door. The tubes are made accessible for cleaning out, etc., by large doors, as *f*, in the boiler front. The furnace and grates *g* are placed under the front end of the boiler. The gases pass over the bridge *h*, along under the boiler into the chamber at the rear, then back through the tubes to the smokebox *b*, and thence to the chimney.

12. Horizontal return-tubular boilers are installed with either *flush fronts* or *overhanging fronts*. These fronts are made of cast iron, or of steel plate formed into the shape for the doors, door frames, and rings that are used for supporting the smokebox doors. In the flush front setting, Fig. 5, the boiler does not extend beyond the boiler front. It is set back of the cast-iron front *a*, so that the gases have a large smoke space *b* to travel through before entering the stack.

The general arrangement of a return-tubular boiler having an overhanging front is shown in Fig. 6 (*a*). In this case the boiler has a steel smokebox *a* that extends beyond the steel front *b*. In such construction the front tube-sheet is installed so that the flange of the tube-sheet *c* extends outwards, as shown in view (*b*). This drawing further illustrates the relative arrangement of the tubes *d* and the diagonal braces *e* that support the flat section of the tube plate, above the tubes, commonly referred to as the *tube-head segment*. The stays are riveted to the boiler shell and tube head. The nozzle *f* is pressed from steel plate, having at the bottom a flange by which the nozzle may be riveted to the shell plate. The upper end of the nozzle has a flange to which the safety valve is bolted. To provide an entrance to the shell for inspection, for clean-

located a drain, or blow-off, *h*, that is employed for removing the water from the boiler periodically and for cleaning purposes. The boiler shown in view (*a*) is suspended from **I** beams *i* that are supported by cast-iron columns *j*. Suitable hanger rods *k* and hanger straps *l* are employed in suspending the boiler. This method of setting a boiler is more flexible than is obtainable with the use of brackets. The rear end is

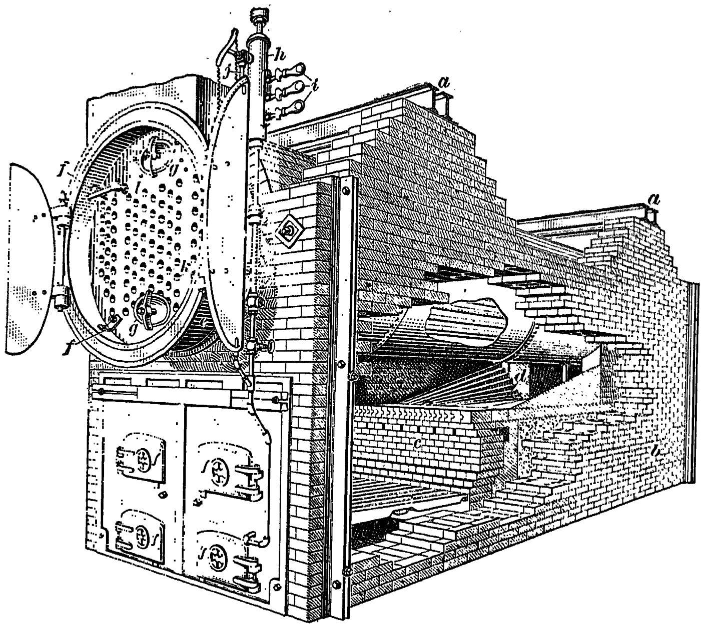


Fig. 7

set from 1 inch to 1½ inches lower than the front end to facilitate draining off the water through the blow-off at the rear.

13. Uniflow Return-Tubular Boiler.—The uniflow boiler is a modification of the horizontal return-tubular boiler. In Fig. 7 is shown a typical installation, with the boiler setting. The boiler is suspended from **I** beams *a* by suitable hangers. A brick setting *b* surrounds the boiler and forms the sides of the furnace. The furnace setting consists also of a bridge wall *c*, and an inverted arch *d* that runs from the bridge wall

The water is fed into the boiler through the connection *l*, placed on the side of the front head above the tubes. The feedwater is discharged downwards between the center and outer tube banks. Circulation of the water and steam is indicated by the arrows. Steam rises directly from the heating surface to the steam space and the cooler water flows downwards between the tubes and replaces the hotter water carried away by the upward circulation. The boiler derives its name from this provision for the circulation of the water.

15. Robb-Mumford Boiler.—The boilers so far described have the furnace outside of the boiler itself, and hence are said

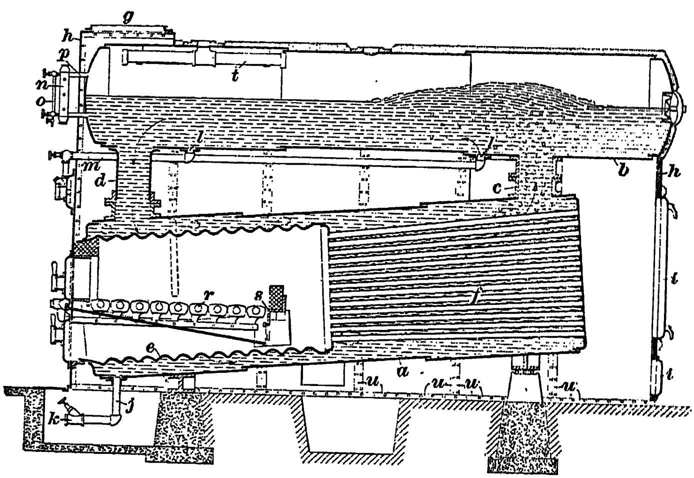


FIG. 9

to be *externally fired*. Many boilers are in use, however, in which the furnace is inside the boiler; such boilers are referred to as being *internally fired*. The Robb-Mumford boiler, shown in section in Fig. 9, is an example of an internally fired horizontal boiler. It consists of two cylindrical drums *a* and *b* connected by the cylindrical nozzles, or necks, *c* and *d*, one at each end. The lower drum *a* contains a cylindrical furnace *e* fitted at one end with a furnace front containing a fire-door and an ash-pit door, and at the other end with a tube-sheet into which are expanded the tubes *f*. The tubes are also expanded into the

arrangement of the devices and piping makes it possible to determine the height of the water level in the boiler at all times. The rocking grates *r* in the boiler furnace are supported at the rear by an arch *s* and at the front by an angle-iron support. A pipe *t*, called the *dry pipe*, is connected to the main steam outlet. It is of cylindrical shape, from 4 to 6 inches in diameter, having a number of holes along the top, through which steam enters in its travel to the steam outlet. The purpose of the dry pipe is to remove water held in suspension in the steam. The casing that surrounds the boiler is built of steel plate with angle-iron stiffeners *u*, and is made in sections that are bolted together. The inside of the casing and the top of the steam drum are lined with non-conducting material.

18. Clyde, or Dry-Back, Boiler.—The Clyde boiler shown in Fig. 10 is entirely self-contained, requiring no brick setting. It was originally designed for marine use, but on account of the small space it occupies it is used in many stationary steam plants. This type of boiler has a very large amount of heating surface in proportion to its grate area. The boiler consists of a large cylindrical shell *a*, its ends being closed with flat heads *b*. The corrugated furnace *c*, commonly referred to as the *Morison corrugated furnace*, is riveted to the front and rear heads, which are flanged inwards for this purpose. Tubes *d* extend from head to head, thus providing heating surface and a means for conveying the gases from the furnace to the uptake or smokestack *e* that connects with the chimney *f*. The smokebox is also commonly called a *breeching*. The flat heads are stayed by end-to-end stays *g* called *through stayrods*, which prevent bulging of the heads. The remaining parts of the flat heads are supported by the tubes, which are expanded and beaded over, and by the furnace flue. The furnace is formed within the flue, and comprises the grate *h*, the ash-pit *i*, and the bridge *j*. The gases of combustion flow to the rear into the combustion chamber *k* and then pass through the tubes to the front and into the uptake *e*.

19. The combustion chamber *k*, Fig. 10, is formed by a thin cylindrical shell attached to the rear end of the boiler, and

is lined with firebrick or thick asbestos millboard, which is light and is not affected by intense heat. The back plate is removable, giving access to the rear ends of the tubes. A door *l* gives access to the combustion chamber for the removal of ashes and soot and for the purpose of examination and repair. The feedwater enters the boiler at *m* and, passing through the internal perforated feedpipe *n*, is discharged downwards alongside the shell in small streams. The various fittings, such as the steam gauge, water column, and safety valve, are not shown in the illustration. The water column and steam gauge would be located conveniently for reading the steam pressure and for determining the water level. The safety valve would be bolted to the nozzle *o*, and the steam pipe to the nozzle *p*. The steam is collected by the dry pipe *q*, which is effective in removing water mixed with the steam. The manhole is placed in the shell at *r*, and handholes are arranged in the front head, at *s*. The blow-off connection is placed at *t*. The boiler is supported by structural members *u*, made of angle iron and plate, and so arranged that each one carries approximately the same weight.

20. Vertical Tubular Boiler.—The vertical, or upright, fire-tube boiler may be considered as a modification of the locomotive type placed on end, and, in common with that type, is self-contained. It has the advantage that it requires less floor space than the horizontal return-tubular type; and, being self-contained, the outer shell can be made as heavy as desired for any working pressure. Vertical boilers are used to supply steam for hoisting engines, power shovels, and other installations requiring a small, compact boiler. The large sizes are employed for power purposes in some of the large power plants; but as a rule the vertical boiler is rather inefficient and hard to keep free from soot. Leakage of upper tube ends often occur, owing to forcing.

21. A common form of vertical boiler is shown in Fig. 11. It consists of a vertical shell, at the lower end of which is the firebox *a*. The lower rim of the firebox and the lower end of the shell are separated by a wrought-iron ring *b*, commonly

the crown sheet of the firebox. The tubes serve as stays to strengthen the flat surfaces of the tube-sheets, and convey the gases from the firebox to the chimney or stack connection *k*. The tubes pass through the steam space and are, therefore, not surrounded by water, as the highest water level is usually at the line *l*. This arrangement is considered a bad feature, because the tubes are liable to become overheated and collapse, when the boiler is forced. On the other hand, the steam temperature in the steam space is increased and drier steam is obtained, as the heat from the tubes slightly superheats the steam; that is, it heats the steam to a higher temperature than that of the water from which the steam is formed. The main steam-pipe connection is made to the flange *m* and the safety valve is bolted by a suitable fitting to the flange *n*. The water column *o*, with its gauge glass and cocks, is connected by the pipes *p* to the steam and water spaces of the boiler. A steam gauge *q* is connected to the steam space by a drop pipe *r* so that the gauge is brought to a suitable position for reading the pressure.

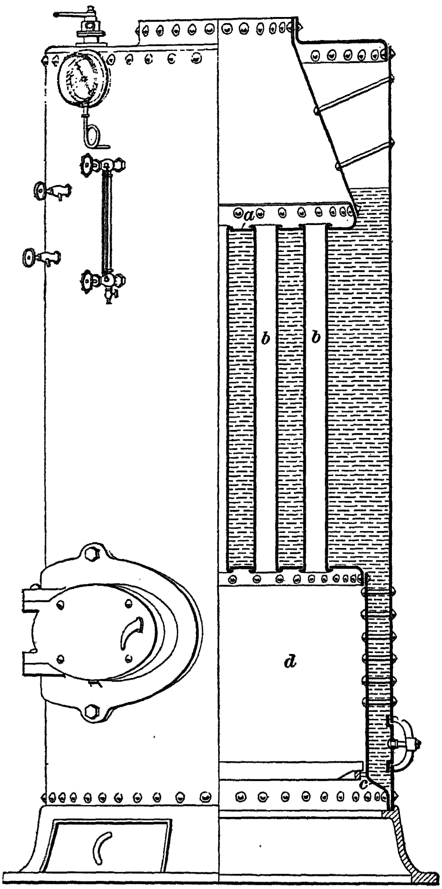


Fig. 12

lips, called beads. The beads prevent the tube ends from burning off and add strength to the staying qualities of the tubes.

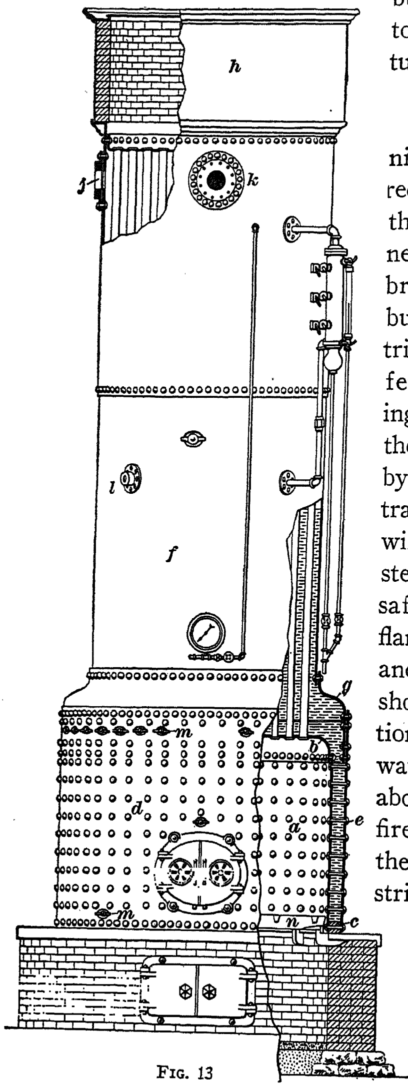


Fig. 13

25. The gases in the Manning boiler, Fig. 13, travel directly from the firebox through the tubes to the smoke connection *h*. The small tubes break up the products of combustion and give a wider distribution of the heat and transfer it rapidly to the surrounding water. The upper ends of the tubes are not surrounded by water, and the heat that is transmitted through these parts will superheat the steam. The steam outlet is at *j*, and the safety valve is connected to the flange *k*. The water column and steam gauge are also shown in their proper positions on the boiler. The feed-water connection *l* is well above the crown sheet of the firebox, being so placed that the colder water does not strike the heated plates of the firebox. Handhole openings *m* are provided in the shell above the crown sheet of the firebox and just above the mud-ring. They are used when it is necessary to clean out the mud and scale that collect on the tube-sheet and the mud-ring. The grates *n* rest

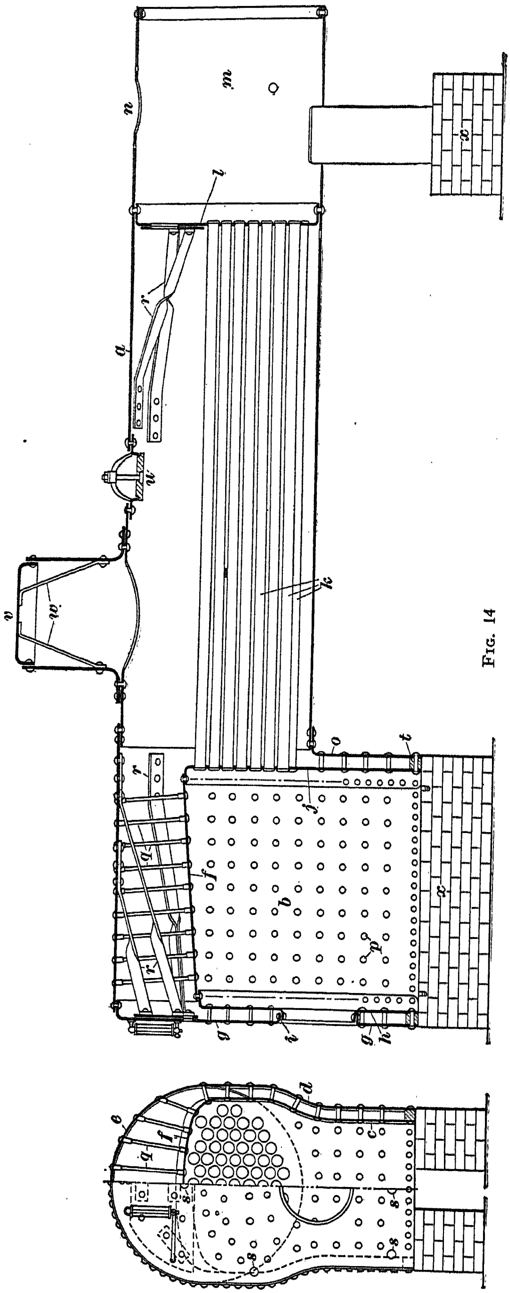


Fig. 14

the dome. In some constructions, threaded stayrods are screwed into the dome head and the shell plate under the dome; but in such a case the dome opening would not be cut out entirely as is shown in the illustration. A number of circular holes would be drilled in the shell plate, to allow free circulation of steam into the dome, but leaving sufficient material between the holes for installing the screw stays. The feed-water may be introduced at any convenient place in the boiler shell below the water-line, usually at the coolest section of the boiler. This boiler is of the semi-portable type that may be moved about on skids, and then mounted on a brick founda-

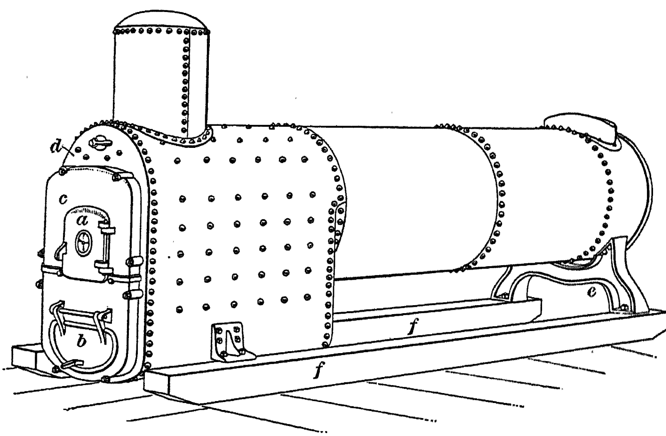


FIG. 15

tion *x*. In the operation of stationary boilers, with the exception of locomotive-type boilers, it is customary to speak of the end at which the firing is done as the front end. In the case of locomotive boilers the smokebox end is called the front end, since it is the forward end of a locomotive.

29. Wet-Bottom Firebox Type.—A perspective view of a semi-portable boiler of the firebox type is shown in Fig. 15. The bottom of the firebox, instead of opening into an ash-pit, is closed by a continuation of the water legs, and hence the furnace is entirely surrounded by water. A boiler thus constructed is said to be *wet-bottomed*. In the particular design shown, the

fire-door *a* and ash-pit door *b* are attached to a cast-iron front *c* which, in turn, is bolted to the back head *d*; with this construction the firebox wrapper sheet is riveted directly to flanges formed on the back head, there being no furnace end or door sheet. The cylindrical part of the boiler is supported by a cast-iron cradle *e*. For convenience of shipment, the boiler is mounted on skids *f*, which may also serve as a temporary foundation. Some wet-bottom boilers have an ash-pit door in the center of the bottom instead of in the back head.

30. Pennsylvania Boiler.—In Fig. 16 is shown a form of boiler that is a combination of a firebox and a return-tubular boiler, and which is known as the Pennsylvania boiler. The firebox, or furnace, has a semicircular crown sheet *a*, which is stayed by solid crown bars *b* having a rectangular cross-section. The water legs are stayed by screw stays, as in locomotive boilers. The gases of combustion pass through the large, short, lower tubes *c* to a combustion chamber forming an extension of the cylindrical part of the boiler, and then return through the small, long tubes *d* to the smokebox *e*, whence they discharge into the chimney. A baffle plate *f* is fitted to the combustion chamber to prevent the hot gases from coming into contact with the upper part of the tube-sheet, which part is not covered by water.

The boiler is self-contained; that is, it requires no elaborate setting. It has the advantage over the locomotive boiler of having a much greater depth of water over the crown sheet, and the heated gases have a longer tube travel, thus making it possible to use a greater amount of the heat from the products of combustion. For convenience in shipment, the boiler is mounted on skids *g*, the cylindrical part of the boiler being supported in a cast-iron cradle *h*, which is utilized when the boiler is set permanently on a foundation.

pressure for which the boiler is constructed. The longitudinal drum is standard, although, where head room is a factor, the cross-drum type is built to meet the requirements.

In Fig. 17 are illustrated the details of construction of the longitudinal-drum Babcock and Wilcox boiler. It consists of one or more horizontal drums *a*, dependent on the size of the

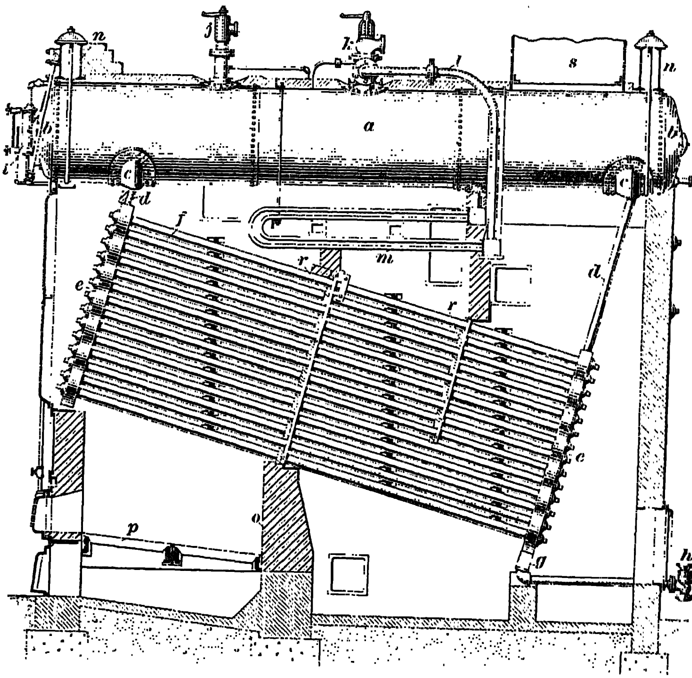


Fig. 17

boiler and its capacity, usually made of three cylindrical courses riveted together with single-riveted seams. These particular seams are called *girth seams*, or *circumferential seams*. The riveted joints running lengthwise of the drum are called *longitudinal seams*. They are made by butting the longitudinal edges of the drum sections together and covering the joints with outside and inside plates, which are riveted together with the shell plate. Joints made in this way are called *butt joints*. The heads *b* close the ends of the drum.

35. The *mud-drum g,* Fig. 17, to which the header *e* is connected, is a steel box $7\frac{1}{4}$ inches square, and of sufficient length to connect the tube-header sections. It collects mud and sediment that settle at the bottom of the vessel. The sediment is removed through handhole openings in the drum or is blown out through the blow-off connection *h.* The pressure gauge and the water column *i* are connected to the drum *a.* A safety valve *j* is attached to the drum and another safety valve *k* is connected to the main steam pipe *l* that leads from the superheater *m.*

The superheater is constructed of pipe coils and headers through which the steam from the steam space of the drum *a* is circulated. The superheater is set directly in the furnace, and is subjected to the hot gases. If at any time no steam should be drawn from the boiler, the superheater would become overheated. The safety valve *k* is provided to prevent this condition. It is set at a pressure slightly below that of the safety valve *j*, and when the pressure rises it will open and permit some steam to flow through the superheater.

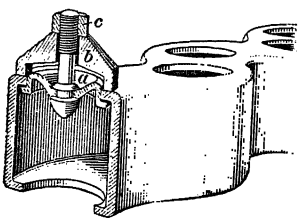


FIG. 20

36. Feedwater is introduced through the front drum head *b,* Fig. 17, and is carried back to the rear of the drum. It flows downwards in the rear header *e,* then through the tubes *f* to the front header *e,* and upwards through this header to the drum *a.* The water that is not transformed into steam again follows the circulation. The steam that is liberated in the drum *a* is stored in the steam space and is drawn off either through a dry pipe or through the superheater *m.*

The method of supporting the longitudinal-drum boiler shown is to suspend the rear and front ends from steel **I** beams *n,* which rest on columns, thus forming a structural frame support independent of the brickwork in the setting. This method allows for expansion and contraction without affecting the boiler or setting. This type of boiler, in common with most boilers

39. The Heine boiler is enclosed by a brickwork setting in the usual manner. The bridge wall *f*, Fig. 21, made largely of firebrick, is hollow, and has openings in the rear to allow air to pass into the chamber *g* and mix with the furnace gases. In the rear wall is the arched opening *h*, which is closed by a door and further protected by a thin wall of firebrick. When it is necessary to enter the chamber *g*, the wall at *h* may be removed and afterwards replaced. The feedwater is brought

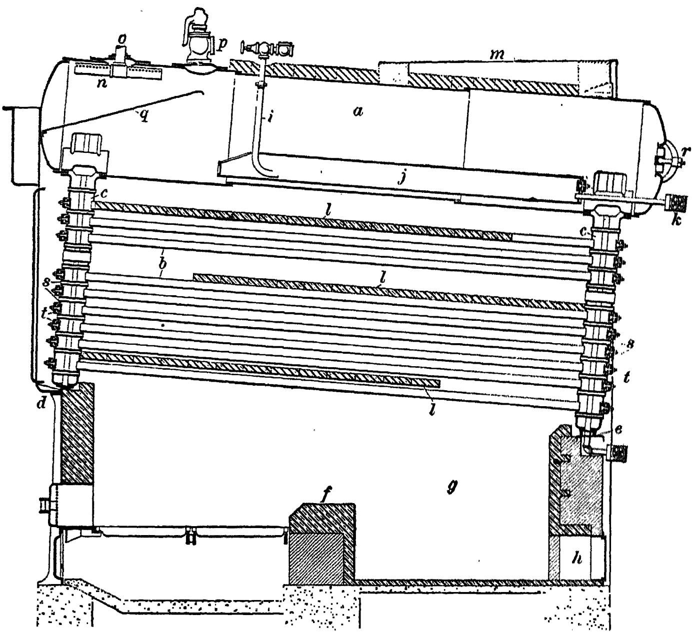


FIG. 21

in through the feedpipe *i*, which passes through the top of the drum. As the water enters, it flows into the mud-drum *j*, which is suspended in the main drum below the water-line and is thus completely submerged in the hottest water in the boiler. This high temperature is useful in causing the impurities contained in the feedwater to settle in the mud-drum *j*, from which they may be blown out through the blow-off pipe *k*. The water passes back out of the open end of the mud-drum and circulates in the same direction as in the boiler shown in Fig. 17.

tubes. In front of each tube a handhole t is placed to give access to the interior of the tube. When a group, or battery, of several boilers is used, additional steam drums are placed parallel to the drums a.

41. Edge Moor Water-Tube Boiler.—The Edge Moor water-tube boiler, shown in Fig. 22, is also made up of tubes, tube headers, and drums. The distance feature in its construction is the tube header a, which is carried above the

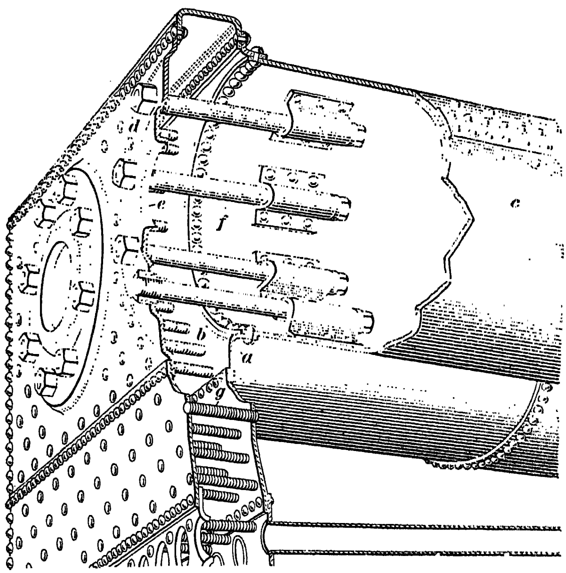


FIG. 23

drums b, thus providing additional steam and water space. The section, Fig. 23, shows the tube-header details and how the drum is arranged and stayed to the header connection. A flange a is turned on the header plate b, into which the drum c is set and riveted. To reinforce the outer sheet d around the manhole opening e, the stays f are installed. All flat plates of the headers are stayed with screw staybolts g, which are screwed into the inner and outer sheets and riveted over. Opposite each tube is placed an elliptical handhole. The hand-

hole plates are removable through their own openings; and through these openings the tubes are cleaned or repaired. Fig. 22 shows the relative arrangement of the tube headers *a*, drums *b*, tubes *c*, baffles *d*, and bridge wall *e*, and a section of the boiler setting *f* with the front structural supports *g*. The grates and other details are not shown. The grate sections would be placed in front of the bridge wall, under the high end of the boiler. The fuel gases travel in the direction of the arrows, upwards around the front tube section, downwards about the middle tube section, and upwards around the rear tube section to the smoke breeching *h*.

42. The Edge Moor boiler is supported by columns or suspended from overhead beams. Column supports for the headers are shown in Fig. 24 (*a*) and (*b*). View (*a*) shows an **H** column used for supporting the front of a battery of boilers. It is placed between the headers and bolted to angle clips *a* that are fastened to the headers. Angles *b* are riveted to the web of the **H** column. A foundation plate *c* is embedded in the concrete floor that forms a base for the column. The saddle support, view (*b*), is placed at the rear of the boilers, under the back headers. The suspension method of supporting the boilers is illustrated in view (*c*). Either **H** or **I** beams *a* form the column supports, and channels *b* form the cross-beams. The channels are bolted together at each end by bolts *c*, and spacers or sleeves are placed between the backs of the channels, through which the bolts pass. The spacers keep the channels apart and in alinement. A special steel sleeve *d* rests on the channels. A hanger bolt *e* passes through the sleeves *d* and *f*, and an adjusting nut *g* facilitates adjusting the boiler so that the headers hang plumb with the supports.

VERTICAL WATER-TUBE BOILERS

43. Bigelow-Hornsby Water-Tube Boiler.—The difference between the Bigelow-Hornsby boiler and those already described is in the tube arrangement and the shape of the tube headers. A typical installation, represented in Fig. 25, is com-

is connected to the adjoining set by circulating tubes *f*, giving the required means for circulation of steam and water. A nest of 21 tubes directly connects the upper and lower tube headers.

Feedwater enters the top rear header through the connection *g*, passes down the rear tubes, and is then carried by the circulation up the tubes in the front tube units. It thus passes through the rear tube units, which are in contact with the cooler gases of combustion, before entering the forward units where the heating surfaces are directly in contact with the fire and hottest gases. Baffle plates *h* are placed between the tubes to change the gas travel.

44. The lower drum headers, Fig. 25, collect the mud and other sediment that settles when the water is heated to a high temperature. Bottom blow-off connections *i* are installed in the lowest part of the drum heads for the purpose of blowing out mud and sediment. Beneath the main drum *a* is shown a superheater *j* made of pipe bent to a **U** shape, with the legs connecting headers *k*. To protect the wrought pipes or tubes from the corroding effect of the gases, cast-iron cover-plates *l*, called grids, are fixed around the superheating tubes. Steam is drawn from the drum *a*, passes down the pipe *m*, and circulates through the **U** tubes of the superheater to the main steam piping *n*, which is connected to the superheater by the pipe *o*.

Owing to the length of the drum and tube-header units, the setting must have high headroom. The tube-header units are suspended from structural members installed outside the boiler setting. Suitable clean-out and inspection doors *p* are provided for the convenient removal of refuse that collects back of the bridge wall *q*, and for the inspection of the boiler sections, which must be made periodically. The furnace in this installation is constructed for firing the fuel with a mechanical device *r*, called a *stoker*. The coal hopper is shown at *s* and the propelling machinery at *t*. The grates of the stoker are inclined.

45. Stirling Water-Tube Boiler.—A well-known type of bent-tube stationary boiler is the Stirling water-tube boiler, shown in Fig. 26. It consists of a lower drum *a* connected with three upper drums *b* by three sets of nearly vertical tubes *c*.

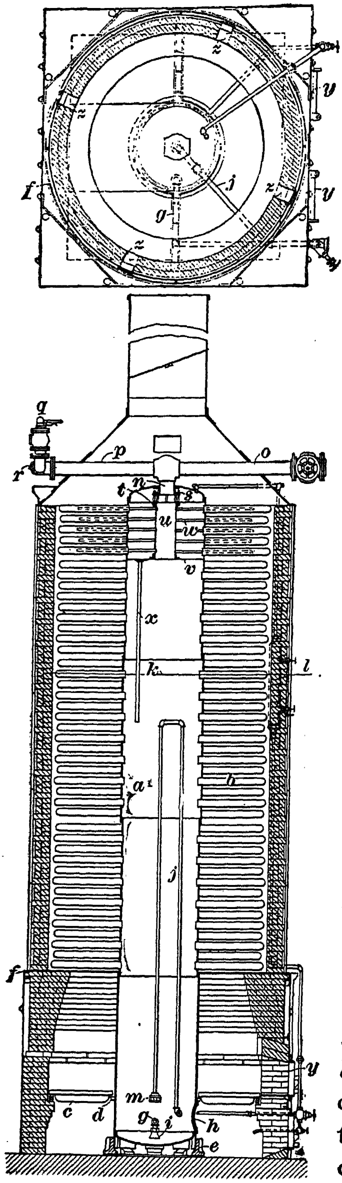


FIG. 27

rear nest of tubes to the drum *a*, which acts as a mud-drum and collects the sediment from the water. From the drum *a* the water passes upwards through the two forward sets of tubes and is vaporized as it rises, the steam passing from the front drum to the middle drum through the upper set of curved tubes *d*, while the unvaporized water circulates between the front and middle drums through the lowest set of curved tubes *d*, and thus the heated water does not again mingle with the comparatively cold water in the drum *a*. The steam collects in the upper drums *b*. A blow-off pipe *k* permits the removal of the sediment. The steam pipe and the safety valve *l* are attached to the middle drum. The chimney connection *m* is located behind the rear upper drum. The water column *n*, with its fittings, is placed in communication with the front upper drum. Each drum is provided with a large manhole *o*.

47. Hazelton Water-Tube Boiler.—The Hazelton boiler, sometimes called the *porcupine boiler*, because of the rather peculiar arrangement of the water tubes, is shown in Fig. 27. It consists of a vertical shell *a*, to which a large number of radial

located on the end of the pipe below the safety valve, which is uncovered to afford ventilation to the interior of the boiler when it is necessary for a man to enter it. The nipple *n* terminates at its lower end in a flange *s*, to which is bolted a blank flange *t* at a distance of several inches. This blank flange closes the top of a short length of large pipe *u* suspended from it.

50. A diaphragm plate *v*, Fig. 27, is attached to the lower end of the pipe *u* and the shell of the boiler and closes the annular space between them. From the central pipe *u* a large number of small pipes *w* radiate horizontally and extend into the boiler tubes nearly to their outer ends. The steam flows from the central pipe through the small pipes into the boiler tubes, and thence backwards into the top of the steam drum, whence it passes out between the two flanges *s* and *t*. A drip pipe *x* is suspended from the diaphragm and extends a short distance below the water level in the boiler. Two firing doors *y* are located at one side of the furnace, and several doors are conveniently located in the brick setting, so that an examination can be made of the exterior of the boiler shell and tubes.

51. Wickes Water-Tube Boiler.—Another form of vertical water-tube boiler, known as the Wickes boiler, is shown in Fig. 28. It consists of two cylindrical drums *a* and *b* joined together by a number of long straight tubes *c*. The tubes are separated by a baffle plate *d* of firebrick, passing through the center of the tube nest, thus dividing the tubes into two banks. The boiler drums are of the same diameter, but differ in height and in the arrangement of the convex heads *e*. The upper, or steam, drum *a* is closed at the bottom with a tube-sheet *f*. The drum *b*, which is the water drum and mud-drum, is much shorter than the steam drum, and its top is closed by a tube-sheet *g*. At the bottom of the mud-drum, a blow-off pipe connection is made at *h* for the removal of mud and sediment. The arrangement of the manholes *i* in both the upper and lower drums permits entering the boiler at its highest and lowest points for inspection, for repairing of the tubes, and for cleaning purposes, as required in the removal of scale from the drums and boiler tubes.

52. The brick setting around the boiler in Fig. 28 is independent of the boiler installation. By this arrangement, the boiler is free to expand and contract without affecting the walls of the setting. The brick wall is surrounded by a steel jacket *m*, and non-conducting material *n*, such as asbestos or magnesia, is placed between the jacket *m* and the brick wall. The boiler is supported by brackets *o* that are riveted to the mud-drum and that rest on a foundation placed under the boiler. Incorporated with the setting are the furnace and grates *p*, so arranged outside of the boiler that the heat and flames have a long travel around the boiler tubes. The flow of the heated gases is produced by the draft of the chimney *q*. They flow around the first bank of tubes in front of the baffle *d*, over the baffle, down about the downcomer tubes, through the breeching *r*, and to the stack. A double swinging damper *s* is installed in the breeching between the stack and the boiler setting, to control the draft or flow of gases. A clean-out door *t* is placed back of the stack, in the setting, so that entrance is made for cleaning, inspection, and repairs to the stack connection. Boiler accessories, such as the water column *u*, with the gauge glass *v* and the gauge-cocks *w*, are attached to the steam drum *a* by the piping *x*. The upper pipe *x* is in communication with the steam space above the highest water-line and the lower is attached below the water level.

53. Cahall Boiler.—The Cahall boiler, shown in Fig. 29, consists of a cylindrical mud-drum *a* and steam drum *b*, which are connected by nearly vertical tubes *c* that form a tube nest having an open space in the center in the form of an inverted cone. In this space are installed deflecting plates *d*, or baffles. The furnace *e* is placed to one side of the boiler, and the gases of combustion surround the tubes, being deflected by the baffles *d* to a sweep nearly at right angles to the tubes. They finally pass out through a central passage in the steam drum to the smokestack. The steam becomes slightly superheated in this steam drum, through coming in contact with the surface of the central passage, which is kept at a fairly high temperature by the escaping gases. The steam drum and mud-drum are connected by an external circulating pipe *f* that enters the steam drum

some distance below the water-line. The feedwater enters the mud-drum and, becoming highly heated, rises through the vertical tubes to the steam drum, where the steam bubbles are liberated.

Some of the water in the lower part of the steam drum flows continually into the circulating pipe, and since this pipe is not exposed to the heat of the fire, the density of the water in it is much greater than the density of the water in the vertical boiler tubes. In consequence, the water is continually flowing downwards and a rapid circulation is promoted. The blow-off pipe *g* is connected to the bottom of the mud-drum, and the blow-off valve *h* is arranged on the outside of the boiler setting. The water column *i*, the gauge-cocks *j*, and the water glass are attached to the drum *b* for determining the water level. A whistle *k* is incorporated with the water column, its purpose being to give an alarm when the water level falls too low in the boiler.

MARINE BOILERS

CLASSIFICATION

54. Steam boilers for marine service are made in a great variety of forms, but there are at least four well-defined types, as follows: Scotch, locomotive, tubular, and water-tube boilers. Each branch of marine service demands a boiler adapted particularly to its requirements. For example, the Scotch boiler is used in freighters and large, slow-moving passenger steamships; the locomotive and tubular types are used in small vessels; and the water-tube types are mainly used in high-speed passenger, freight, and war vessels.

FIRE-TUBE MARINE BOILERS

55. Scotch Boilers.—The Scotch boiler is distinctively a marine boiler. It is of the fire-tube type and is internally fired, the number of internal furnaces varying from one to four,

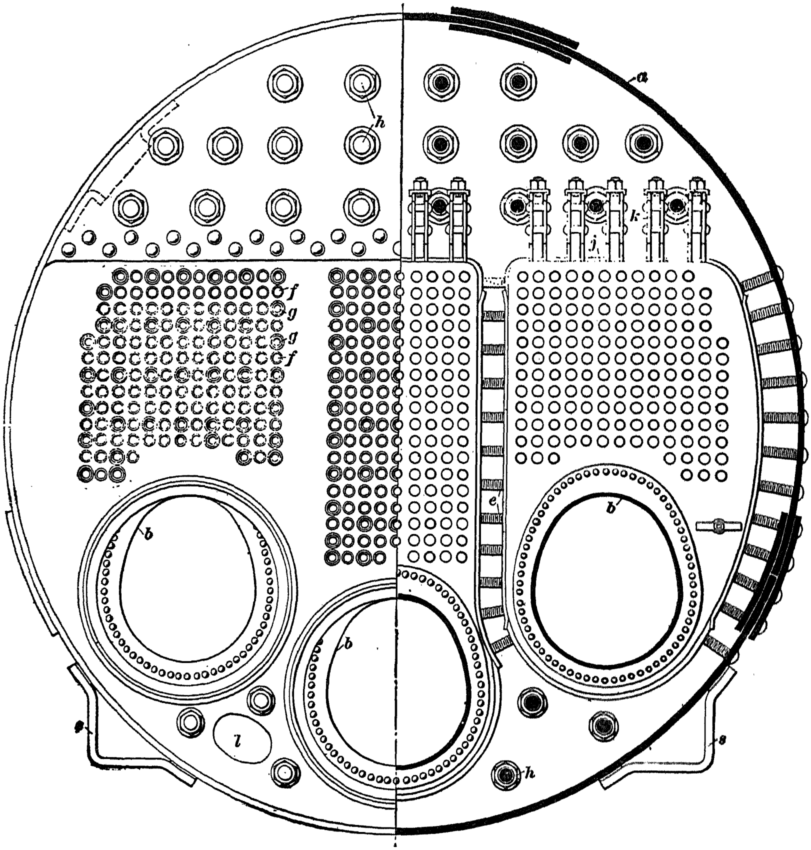


FIG. 30

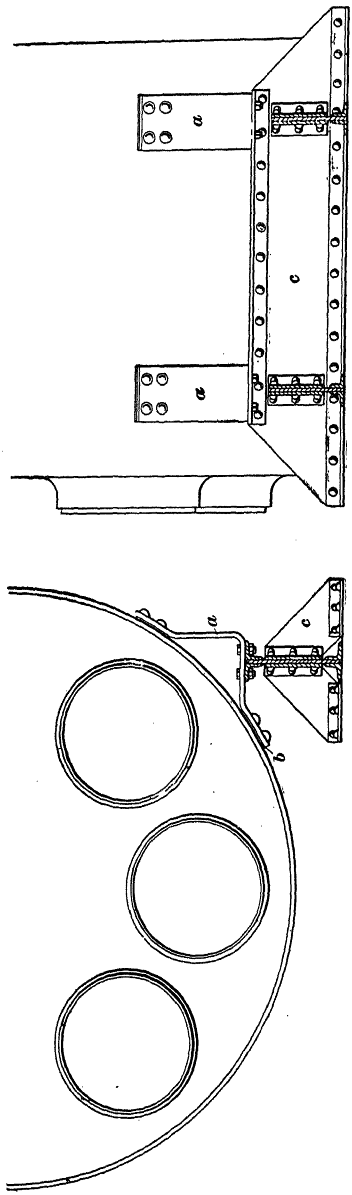


FIG. 32

57. Owing to the size of the boiler heads, they are usually made in two or three sections and riveted together. The flat sections of the rear and front heads are supported by large end-to-end stays *h*, Figs. 30 and 31, which are fitted with inside and outside nuts and washers. The sides of the outer combustion chambers are stayed to the shell plate, and the rear plates of these chambers to the back head *i*. The crown sheets *j* are supported by steel girder stays, or *crown bars*, *k*. The manholes *l* give access to the boiler for inspection and cleaning the various boiler parts. Furnace details, such as the grate bars *m* and dead plates *n*, are placed within the corrugated flues *b*. It is necessary to make the grates long in order to provide the necessary grate area. A cast-iron plate *o* supports the rear ends of the grate bars and also carries the sectional bridge wall *p*, which is made up of a series of cast-iron sections set side by side across the furnace. Slots between adjacent sections admit air from the ash-pit into the current of gases passing

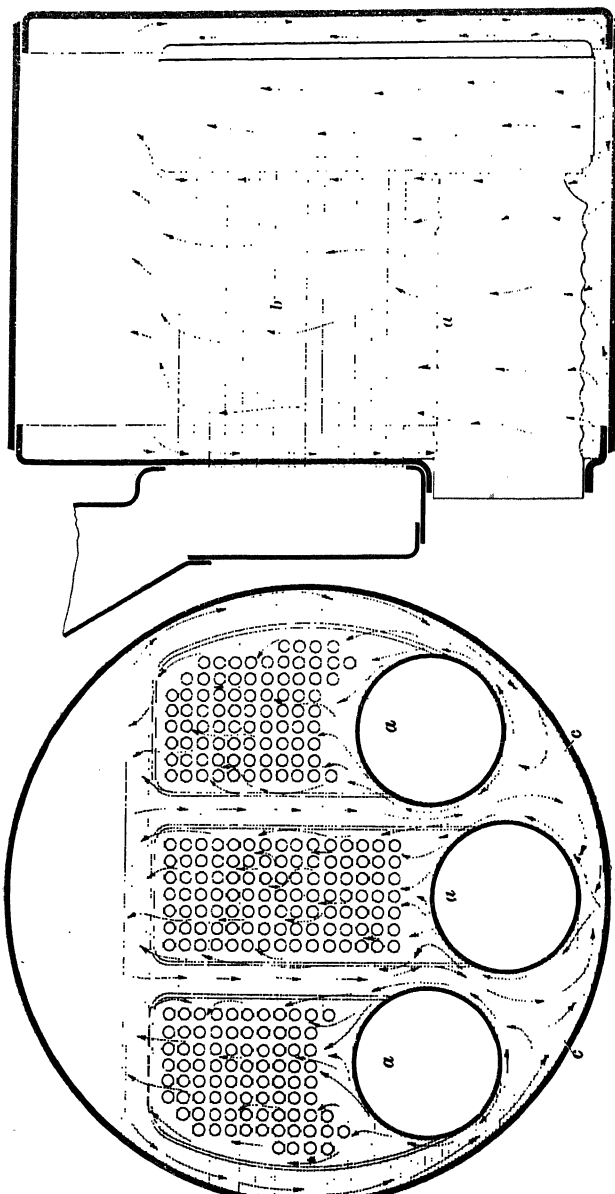


FIG. 33

61. On account of the high steam pressures used in modern marine engines, the marine boiler must be carefully designed for strength. It is likewise necessary to reduce its weight and size to the lowest possible limits. The following data relating

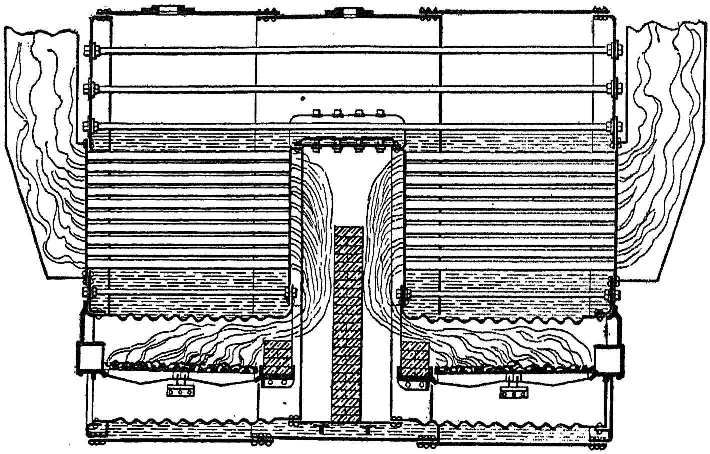


FIG. 35

to the boilers of a naval vessel will give an idea of the principal dimensions of a Scotch marine boiler made of Siemens-Martin steel.

Diameter of shell	15 ft. 2 in.
Length of shell	9 ft. 6 in.
Working pressure	135 lb. per sq. in.
Thickness of shell plates	$1\frac{5}{32}$ in.
Thickness of heads	$\frac{7}{8}$ in.
Number of furnace flues	4
Diameter of furnace flues	3 ft. 1 in.
Thickness of furnace flues	$\frac{15}{32}$ in.
Diameter of stayrods	$1\frac{15}{16}$ in.
Diameter of staybolts	$1\frac{1}{4}$ in.
Number of tubes	490
Diameter of tubes	$2\frac{1}{2}$ in.
Length of tubes	6 ft. 8 in.
Heating surface	2,500 sq. ft.
Weight without water	about 40 tons

For the sake of safety, the Scotch type of boiler must be made extremely heavy and bulky when high steam pressures

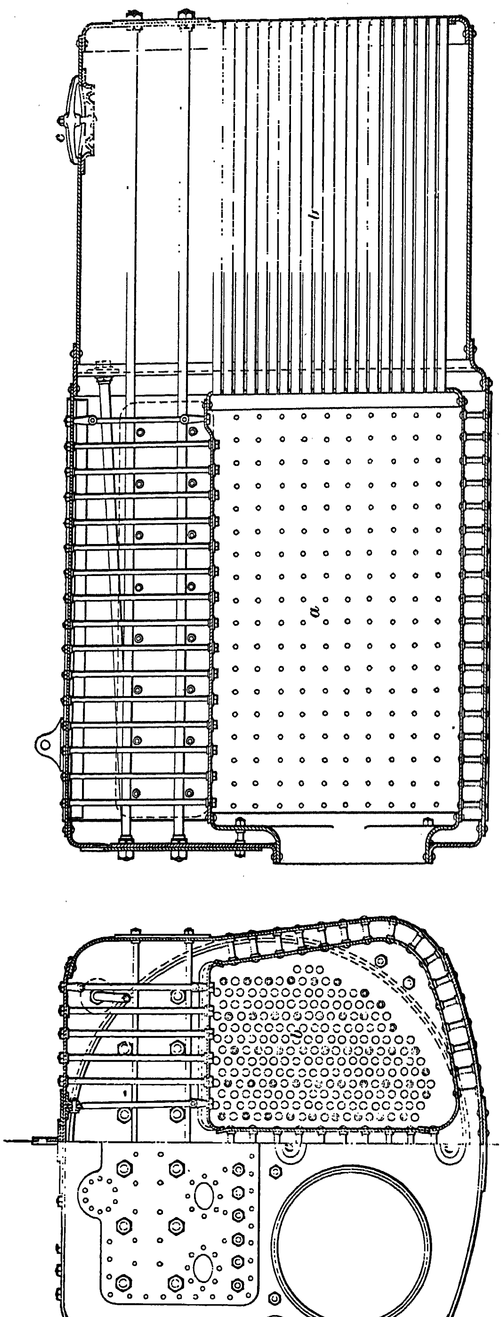


FIG. 36

considerably to the heating surface, and assist in staying and strengthening the flat top of the combustion chamber. They are made tapering to enable the flange at the lower or smaller end of the tube to be passed through the opening in the top sheet of the combustion chamber while the boiler is under construction. The tapering form, with the large end uppermost, also facilitates the release and discharge of the steam that is generated within the tubes, which are called *Galloway tubes*.

66. The heads of the boiler in Fig. 37 are braced by the tubes *e*, the furnace flues *c*, the longitudinal braces *g*, and the diagonal braces, or palm stays, *h*. The palm stays are made of round bar iron or steel forged with flat ends. In some cases, they have palms *i* at the ends, which are riveted to the shell and the head of the boiler; in other cases, they have a palm at one end only and are threaded at the other end. When they are made in this way, the palm end is riveted to the shell of the boiler and the threaded end passes through the head, with a nut on each side of the plate, as shown at *j*. The flat top of the combustion chamber is braced by the sling stays *k*. The sides and bottom of the combustion chamber are secured to the shell of the boiler by the staybolts *l*. The Clyde, or dry-back, boiler described in a preceding article is another boiler of the tubular type employed on small vessels.

WATER-TUBE MARINE BOILERS

67. Types of Water-Tube Marine Boilers.—The water-tube boilers in marine service resemble the water-tube boilers already described and possess the same advantages and disadvantages. Boilers of this type are classified as small-tube and large-tube; horizontal, vertical, and inclined; and as having straight tubes or bent tubes. The general custom is to designate marine water-tube boilers as either large-tube boilers or express boilers. Large-tube boilers, considered suitable for big ships, have tubes $1\frac{7}{8}$ inches or larger in diameter. Practically all boilers of this type have straight tubes. Express boilers are made of small tubes, from 1 to $1\frac{3}{8}$ inches in diameter.

some bent-tube boilers it is necessary to remove sound tubes in order to replace a tube in one of the inner rows. Bent tubes permit a design that makes a lighter and more compact boiler than straight-tube types; hence, they are used for express boilers. Moreover, bent tubes are less liable than straight tubes to injury from expansion and contraction due to the severe operating conditions to which boilers of this type are subjected.

70. Belleville Water-Tube Boiler.—One form of large-tube boiler, known as the Belleville boiler, is shown in Fig. 38. It consists of a number of nearly horizontal tiers of water tubes *a*, screwed or expanded at each end into return bends *b*, making a series of zigzag inclined tubes, beginning at the top of the furnace door and ending at the steam drum *c*, which is located above the tubes. There is a handhole in each of the front bends or connecting boxes *b*. The mud-drum *d* stands vertically, and is located in front of the boiler and below the lowest tubes. The top of the mud-drum is connected to the bottom of the steam drum by a vertical pipe *e*. From the side of the mud-drum, a rectangular feedpipe *f* extends across the front of the boiler, joining each vertical tier of water tubes *a*. The mud-drum blow-off is at the center of the lower head.

71. The Belleville boiler is enclosed in a steel casing, as shown in Fig. 38. The fire-box is arranged below the tubes and runs their full length; the grate bars *g* slope downwards toward the rear. The products of combustion pass upwards between the tubes, thence about a superheater, and out near the top of the casing, as indicated by the arrows. Baffle plates *l* of steel or tile are fitted in the nest of tubes to deflect the hot gases, in order that the entire surface of the tubes may receive the benefit of the heat. The feedwater enters at one end of the steam drum and flows into a shallow pan *h*, then downwards through the external circulating pipe *e* to the mud-drum, and into the rectangular feedpipe *f*; thence it continues through the steam coils to the steam drum. The outlets of the water tubes in the steam drum are several inches above the bottom of the drum, so that the steam will not mingle with the comparatively cool water in the drum.

72. The water passes into the mud-drum of the Belleville boiler through a non-return valve, and then to the bottom and up around a vertical baffle plate. The bottom of the drum forms a settling chamber, into which much of the sediment is deposited. The non-return valve keeps the water circulating in the same direction through the water tubes even when the ship is rolling. It also regulates the direction of flow when steam is being raised. The casing of the boiler is made of steel plates riveted together. Angle irons are used at the joints for stiffeners. The upper part of the casing is lined with magnesia and asbestos, and the lower part next to the fire with firebrick.

This kind of boiler has very little water capacity, and hence it is usually fitted with an automatic feedwater regulator. In operation, it requires very close attention. There is a strong upward flow of steam and hot water as they pass from the tubes into the steam drum. The pan *h*, Fig. 38, and its curved cover *j* serve as a deflector over the openings of the tubes to prevent the water from being carried out through the steam nozzle *k* on the top of the drum.

73. Babcock and Wilcox Marine Boiler.—The Babcock and Wilcox boiler of the mixed-tube type, built for either coal or oil burning, is one that meets the requirements of the British Admiralty, and is largely used in the United States in a variety of vessels. The dry weight of this boiler is much less than that of the Scotch boiler, averaging less than 20 pounds per square foot of heating surface as compared with 40 to 50 pounds per square foot for the Scotch boiler. The weight of water within the boiler ranges from 3 to 5 pounds per square foot of heating surface as compared with 17 to 20 in the Scotch type; hence, the space occupied by the Babcock and Wilcox marine boiler is considerably less than that occupied by the Scotch boiler of equal power.

The general features of construction, shown in Fig. 39 (*a*) and (*b*), are similar to those of the land boiler. The cross-drum *a* is placed at the front and is connected to the tube headers *b* by circulating tubes *c*. Each section of the front header *b*

is connected to the mud-drum *d*, by a short nipple *e*. At each end of the steam and water drum *a* is a manhole *f*. Directly over the furnace, in oil-burning boilers, the lower tubes *g* are inclined at an angle of 18° with the horizontal, while those above are inclined 15° with the horizontal. This difference in inclination leaves a space at the front of the boiler for the brick or tile baffle plate *h*.

74. As the tubes of the boiler in Fig. 39 are straight and accessible from each end, they are easily inspected and repaired. Handhole plates *i* are placed in the outside sheet of each tube header and opposite the tube openings. The circulation in the boiler is rapid and the steam produced is remarkably dry. Feed-water enters the drum *a*, descends through the front header, passes into the tubes, flows up through the back tube header, and through the horizontal tubes *c* into the steam and water drum *a*, striking the baffle plate *j*. The downcomers *k* also assist in promoting the circulation. These pipes connect the drum *a* and the mud-drum *d*. Mud and sediment are blown off through a blow-off valve and piping attached to the mud-drum. Handhole plates are fitted to each end of the mud-drum for cleaning and inspection purposes. The boiler furnace is encased in firebrick *l* and backed with a steel casing *m*, reinforced with angle irons *n*. The back tube header *b* is usually not covered, as boilers are usually set back to back, with a casing common to both, thus economizing room. Separate stack connections are made by installing uptakes leading from each boiler to the stack. Baffles *o* cause the gases to flow three times at right angles to the tubes. The boiler fittings, such as the steam gauge, water column, etc., are not shown. The devices *p* are oil-burning apparatus.

75. Babcock and Wilcox Box-Type Marine Boiler.—The distinctive feature in the construction of the Babcock and Wilcox box-type marine boiler, shown in Fig. 40 (*a*) and (*b*), is the arrangement of the steel headers *a* and *b*. They take the place of drums usually fitted in what is known as the **A** type of marine boiler, and are either of straight box form or of corrugated form. They run crosswise, as shown at *a*, or longitu-

dinally, as shown at *b*. Each header opposite a bank of tubes is so fitted with handhole plates *c* that examination, cleaning, and repair of the tubes may be made without interfering with other tubes. The view (*a*) is a conventional view of the boiler. The sectional drawing to the right of the vertical center line illustrates the interior arrangement of the combustion chamber and its side walls *d* and grates *e*. The tubes *f* are straight, except the end sections that join to the drum *g*, which are curved in order to have the tubes enter the drum at right angles to the contour of the shell. The view to the left of the center line indicates the details of the boiler covering, showing the steel casing *h*, fire-door *i*, and ash-pit door *j*. A lengthwise sectional elevation of the boiler is shown in view (*b*). Baffling of the gases is obtained by the use of baffle plates that are placed between the tubes and parallel to them.

76. Babcock and Wilcox Drum-Type Boiler.—In the Babcock and Wilcox cross-drum water-tube boiler, shown in Fig. 41 (*a*) and (*b*), the arrangement of the water drum *a* and steam drum *b* is such that the boiler is fired from the water-drum side. This type is an efficient design and can be operated with oil or coal as fuel. The water drum *a* is made in two sections; the lower section is semicircular and the upper part is made of heavier metal and is bent to a larger radius except at the corners, where the joint is made. This shape of the upper section permits a better arrangement and a larger number of tubes *c* in the boiler than would be possible if the section were made semicircular. At each end of the drums *a* and *b* is fitted an elliptical manhole plate *d*. The tubes *c* are bent at both ends, so that they will fit properly into the drum shells and have a good seat in the boiler plate. The bent sections have the advantage of yielding uniformly with the stresses set up by expansion and contraction. The gases are directed by baffles *e*, which are set perpendicular to the tubes, this arrangement causing the gases to make three passes around the tubes before they reach the smoke breeching *f*, which is brought forwards over the water drum *a*. The boiler setting *g* is arranged for oil burning, the oil burners being located at suitable open-

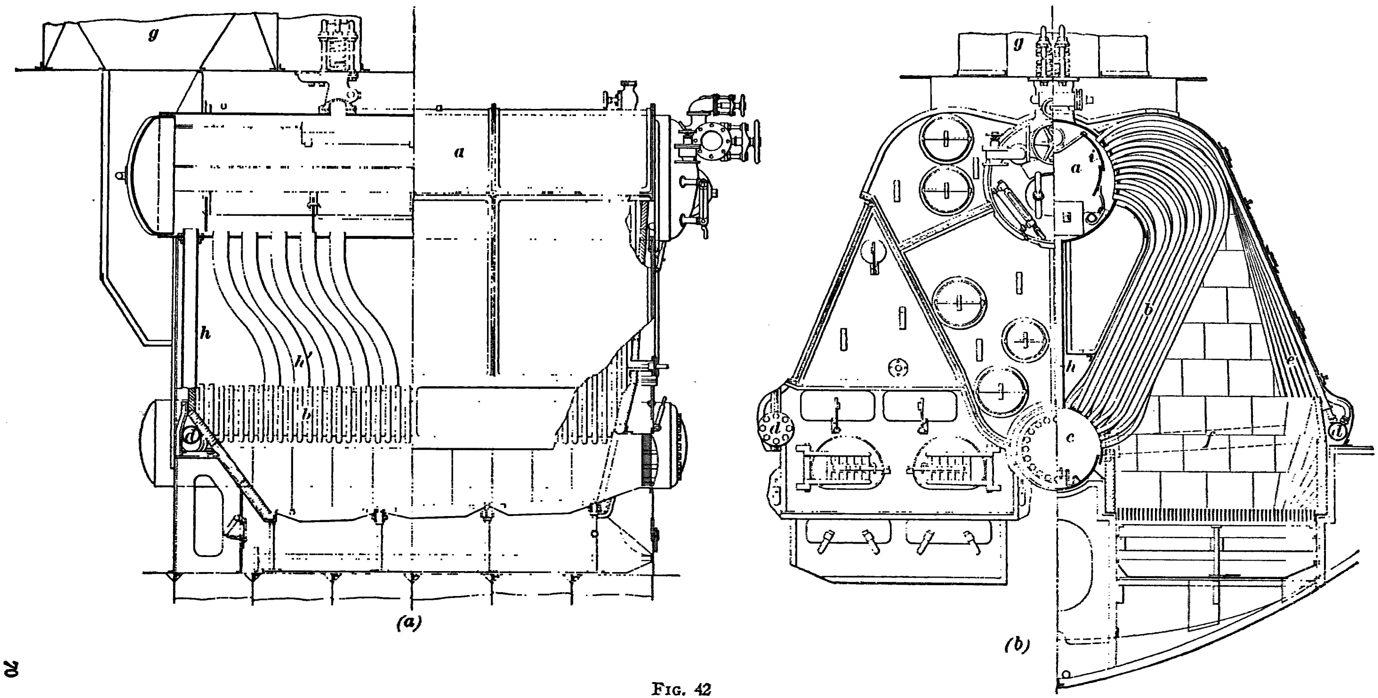


Fig. 42

water drum *a* is connected to three lower drums. The bent tubes *b* connect the two outer drums *c* with the drum *a*, and the tubes are numerous, thus giving a large effective heating surface. The central drum *d* is connected to the drum *a* by bent tubes *e* and straight tubes *f* that form downcomers. Large downcomers *g* also connect the drums *a* and *c*, and assist very much in promoting rapid water and steam circulation. All of the tubes *e* and the downcomers *f* and *g* discharge into the steam drum below the water level, but only a few of the tubes *b* do this. As shown in view (*a*), most of the tubes *b* discharge directly into the steam space of the drum *a*. The tubes are formed to a large curvature and are therefore less liable to be damaged by expansion and contraction. The gases travel from the furnace in

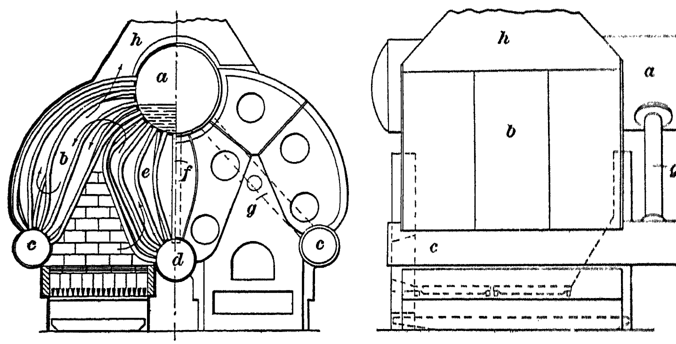


FIG. 43

the direction of the arrow and finally pass out through the breeching *h*. Baffle plates are installed between the tubes to cause the gases to travel as shown.

79. Modified Thornycroft Boiler With Superheater.—The distinctive feature of the modified Thornycroft boiler shown in Fig. 44 is the tube arrangement. View (*a*), to the left of the vertical center line, shows the interior of the boiler. The arrangement of the boiler front, superheater, and smoke breeching is illustrated to the right of the vertical center line. A rear view of the boiler is given in (*b*). The boiler is composed of an upper drum *a* and lower drums *b*, connected by the circulating tubes *c*. These tubes are straight, to the point where they

join the lower drums *b*, at which point they are curved so as to fit properly into the holes in the drum. The outer rows of tubes *c'* are bent to a larger curvature and are used to baffle the gases as well as to increase the boiler heating surface. All of the tubes *c* and *c'* discharge into the water space of the upper drum.

80. The superheater drums *d*, Fig. 44, are placed outside of the boiler front, parallel with the boiler tubes. The sectional view, taken on the line *x x*, illustrates the **U** formation of the superheater coils or tubes *e*, and shows how the ends are set into the drum *d* of the superheater. The coils *e* are set directly on each tube bank, and are so connected to the steam drum *d* that the steam is drawn from the drum and circulated through the superheater coils. As the coils are directly in the path of the hot gases, the temperature of the steam is greatly increased. To convey the steam from the drum and superheater, suitable piping and pipe flanges must be installed. In view (*c*) bent pipes *f* are shown connecting the steam space of the drum *a* and the flanges *g* of the superheaters; also, bent pipes *h* connect the main steam piping *i* with the steam outlets *j* of the superheaters. This arrangement of the superheater coils and pipe connections with large bends makes the installation flexible, so that the pipes and bends give readily with the expansion and contraction stresses arising in the operation of the boiler. The superheater outlet into the main steam pipe is fitted with a safety valve. View (*a*) shows a sectional view of the superheater tubes with the drum removed, and the full front view to the right of the center line indicates the position of the superheater drum, with the pipe flanges *j* and *g* riveted thereto.

81. For the purpose of cleaning the steam and water drums, manholes *k*, Fig. 44, are provided in the heads of the drums. These openings also give access to the boiler for inspection and repairs. The furnace is built for burning fuel oil and is lined with firebrick *l*. Oil-burning equipment, such as the oil piping and the burner nozzles *m*, is arranged at the front of the boiler. The boiler casing *n* is made of two thicknesses of sheet steel, with asbestos or some other non-conductor between.

of combustion pass between the tubes to the smokestack *f* at the rear of the boiler. The boiler casing *g* is of iron and steel lined with non-conducting material. There is also an external casing *h* so arranged that before entering the furnace the air for supporting combustion enters the opening *i* and flows between the casings *g* and *h*. This aids materially in keeping down the temperature of the boiler room by preventing the radiation of heat.

83. Yarrow Water-Tube Boiler With Superheater.—A recent development of the Yarrow boiler adopted by the British Admiralty, is illustrated in the sectional view (*a*) and the side view (*b*), Fig. 46. It is installed with a superheater, and except for the lower drum construction, which is cylindrical in form, and the tube arrangement, it resembles the type just described. It is used for small speedy war vessels and large battleships and cruisers. The water, or generating, tubes *a* are straight, except the bottom row nearest the fire, which are bent. The tubes connect the water drums *b* and *c* to the steam and water drum *d*. As the water drums *b* and *c* are circular, the upper plate section *e* must be made heavier so that the tubes will have sufficient bearing area to insure steam-tight connections, and also to give the required strength to the tube-plate sections. The superheater drums *f* and *g* are also cylindrical and run parallel with the water drums *b* and *c*. The superheater tubes *h* are bent to a **U** shape and their ends are expanded into the superheater drums. To do this work to the best advantage, handhole plates *i* are installed opposite the superheater-tube openings, and through them the tubes are expanded. A downcomer *j* connects the drum *f* of the superheater with the steam pipe *k* inside the steam space of the boiler. Steam is drawn through the pipe *k* and the downcomer and circulates through the drum *f* and the tube sections of the superheater to the drum *g*, which is connected with the main steam stop-valve *l*. An auxiliary steam pipe *m* is also arranged in the steam space of the steam drum, to which is also fitted an auxiliary steam stop-valve *n*. The auxiliary steam feed piping and valve are used in case it is necessary to cut out the superheater for repairs.

breeching, and where there are a number of boilers set in a battery, the breeching is made so that it receives the gases from all the boilers in the battery. This breeching connects directly with the stack. Fuel-oil burners c' are installed at the front of the boiler. Attached to the water drums are boiler supports d', shaped to fit the contour or outline of the drum shell and made with flat bases for bolting down. The boiler is covered with a steel jacket composed of two steel plates with asbestos between, and stiffened by angle irons. The exposed parts of the drums are covered with non-conducting material, commonly called *lagging*. The bottom of the furnace is composed of firebrick laid on steel plates e', called a pan. A layer of asbestos is placed between this plate and the bottom steel plate f'.

86. Normand Water-Tube Boiler.—The Normand boiler, shown in Fig. 47 (a) and (b), is considered one of the most efficient small-tube boilers. It is largely used in small war vessels of the speedy type by France and to some extent by the United States. The dry, or empty, weight of the boiler, as fitted for oil burning, with steam and water accessories, but not including the uptake and stack connections, is approximately 11 pounds per square foot of heating surface. The weight of water under steaming conditions is about 2 pounds per square foot of heating surface. The boiler is of the **A** type, having a main steam and water drum a and water drums b connected by generating tubes c and a downcomer c'. These tubes are small in diameter and bent so as to form an arch-shaped nest of tubes above the furnace. To the drum a is riveted a steam dome d. The steam in passing to the steam dome strikes the baffle plate e, which aids in preventing the very moist steam from entering the main steam outlet. The dome head is supported by the stays f. The feedwater enters the drum a through the valve connections g and piping g'.

87. A scum blow-off pan h, Fig. 47, is located at the given water level, as indicated in view (a), and a blow-off valve i is installed for the removal of scum, grease, and oil, as required. The gauge glass j is attached to the steam and water drum a and gauge-cocks k are also so placed that the water level can be

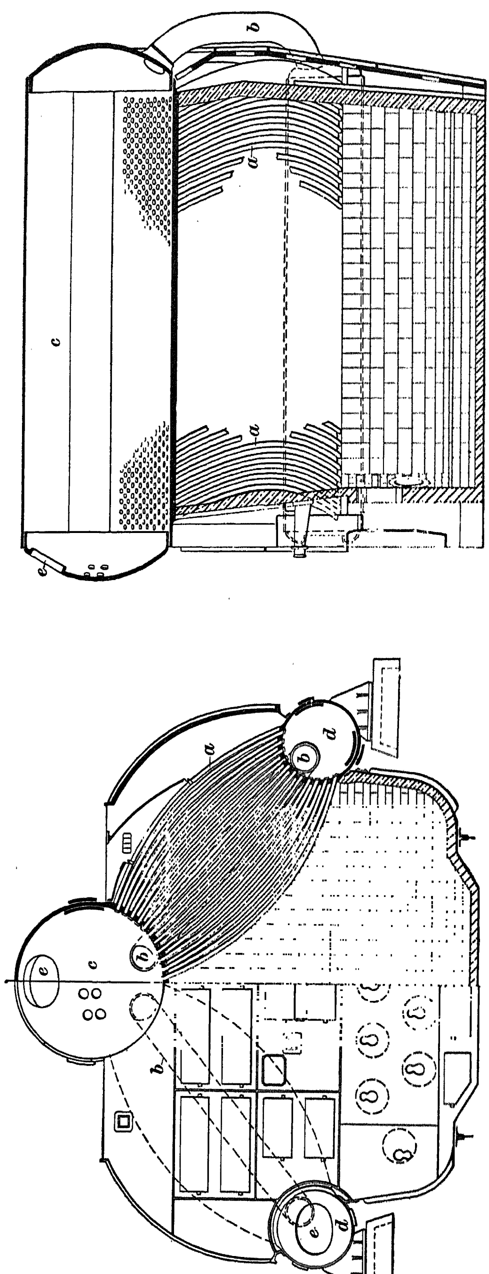


Fig. 43

LOCOMOTIVE BOILERS

89. Classes of Locomotive Boilers.—The locomotive type of boiler is used to the exclusion of all other types in railroad work. It is made in three general forms, known as the *straight-top boiler*, the *extended wagon-top boiler*, and the *conical boiler*. Any one of these forms may have either a Belpaire firebox or a wide firebox.

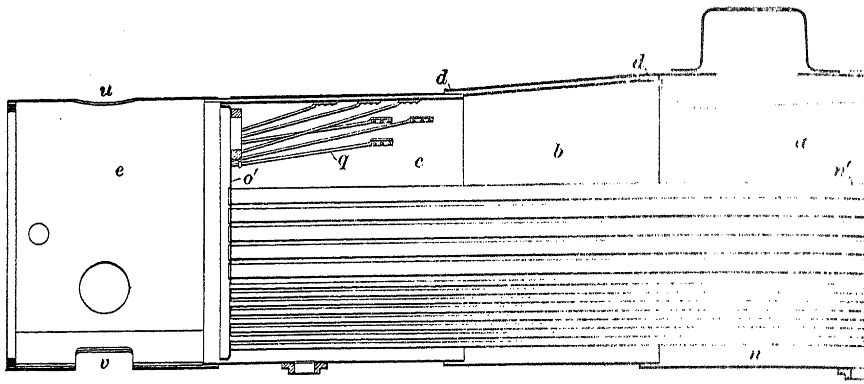
90. Straight-Top Boiler With Wide Firebox.—In Fig. 49 is shown the straight-top locomotive boiler with wide firebox. The general construction is similar to the other types of locomotive boilers. The shell courses *a* are of uniform diameter, and as the courses are straight instead of tapering, the boiler is designated as a straight-top boiler. The firebox is known as the wide firebox on account of its shape, being shallow and extending beyond the driving wheels of the locomotive at the sides. A boiler of this shape, designed for burning anthracite, is known as the *Wooten firebox*. In some of the designs the roof sheet *b* slopes toward the back head *c* instead of being straight, as illustrated. The bottom of the shell course adjoining the firebox is also made tapering in some designs, to furnish more water space around the tubes and the forward end of the firebox. The back head *c*, throat sheet *d*, and door sheet *e* are flanged so as to fit the firebox side sheets properly. The door ring *f* is riveted to the flanges of the door openings in the back head and door sheet. The crown sheet *g* slopes toward the door sheet, to which it is riveted. Crown stays support the roof and crown sheet against internal pressure and the stays *h* support the flat surfaces of the side sheets and the heads of the firebox.

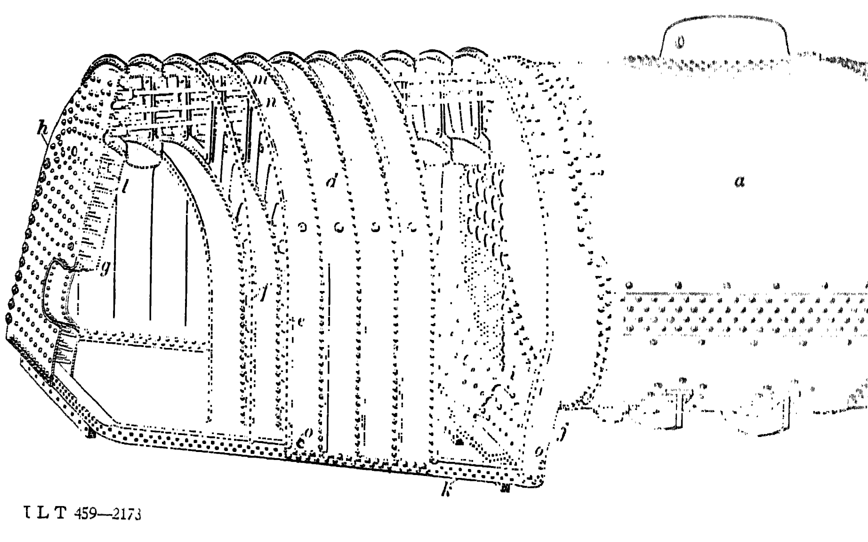
91. The back head is also supported by diagonal stays *i*, Fig. 49, which are attached to **T**-iron braces *j* that are riveted to the back head. A number of washout holes *k* are arranged in convenient places in the outer sheets of the firebox for the purpose of cleaning the crown sheet and removing mud and other sediment from the mud-ring *l*. The projecting lugs of the mud-ring at the back-head and throat-sheet ends are used to attach

boiler, its name being taken from the shape of the tapering top section of the course *b*. The dome in the wagon-top type was placed on the top of the firebox and required special staying. The use of the cylindrical shell *a* next to the firebox, and the setting of the taper course forward, permitted the dome to be installed on the cylindrical shell, in front of the firebox. To distinguish this arrangement of shell courses from the earlier wagon-top boilers, the type illustrated is called the extended wagon-top boiler.

93. The firebox shown in Fig. 50 is known as the Belpaire firebox. The top sheet *f*, called the *roof sheet*, and the crown sheet *f′* are made flat, or with a slight curvature. The corners *g* of the crown sheet are bent to a slight radius, and sufficient material is allowed to form a lap joint, connecting the inside firebox side sheets *h* and the crown sheet. The roof-sheet corners *g′* are rolled to a larger radius and with depending sides that butt against the outer side sheets *h′*. By the use of cover-plates *i* and *i′*, commonly called *welt straps* or *butt straps*, the joint is riveted, forming a butt joint. The inner and outer sheets of the firebox run practically parallel and their flat surfaces are supported by straight stays *j*. Transverse stays or cross-stays *j′* support the flat surfaces between the roof-sheet corners and the outer side sheets.

94. The door end of the inside firebox, Fig. 50, is closed with a flanged head *k*, called a *door sheet*, that has a flanged opening turned near the center of the head for the door connection. The outside head *k′*, called the back head, is riveted to the outside side sheets. It is also flanged for the door opening so that when the two flanged heads are relatively arranged and riveted to the firebox, the flanges of the back head and the door sheet overlap to form a riveted connection called the door ring. The flat surface of the back head above the plane of the crown sheet is braced by **T** irons *l*. A flanged sheet *m*, called the throat sheet, connects the outside sheets of the firebox to the bottom of the shell *a*. The throat sheet is made in different shapes, depending on the form of the firebox. Usually it is flanged so that it fits around approximately one-half of the shell. For the





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the first shell course *c*. From this arrangement of the shell courses, the term conical boiler has been given to designate the boiler.

The Jacobs-Shupert firebox shown in the illustration is a patented sectional firebox having the inner and outer sides and top made up of a series of bent channel shapes *d* with depending flanges. Between the channels and riveted thereto are stay sheets *e*. By the use of this construction, no additional staying of the side sheets is required. To permit circulation of the steam and water between the channels, openings *f* are cut in the stay sheets *e*. The door sheet *g*, back head *h*, tube-sheet *i*, and throat sheet *j* are flanged so as to fit the upright flanges of the channels, to which they are riveted, as shown. The bottom edges of these sheets are straight and are riveted to the mud-ring *k*. The back head and door sheet are stayed together with the screw stays *l*, and the upper section of the back head, which is a flat plate, is supported by the diagonal stays *m*. The stay plates *e* are cut out so as to allow the diagonal stays to extend from the roof of the firebox to the back head. Sling stays *n* are used to stay the sections of the channel plate, left weakened by the removal of the solid plate sections of the sheets. Wash-out plugs *o* are installed above the mud-ring and in the outside channel sections in line with the crown sheet of the inside fire-box plates.

98. The tubes of locomotive boilers range from 6 to 22 feet in length, and may be made of steel or iron. The tubes of stationary boilers of this type are usually 3 to 3½ inches in diameter. The tubes of stationary locomotive boilers are not spaced as closely as in locomotive boilers of the railroad type. With the smaller diameter and larger number of tubes, steam is generated more rapidly than in the stationary types, small tubes proving more efficient in breaking up the fuel gases and in conducting the heat more effectively to the large body of water in the boiler.

thereby lowering the pressure in the boiler. When the pressure is lowered to such an extent that the upward pressure on the disk no longer exceeds the downward pressure, the valve closes. There are three ways of applying pressure to the disk to hold it to its seat: (*a*) By a dead-weight; (*b*) by a weight acting on a lever, and (*c*) by the action of a spring. According to these methods of applying the downward pressure, safety valves are divided into three classes, known as *dead-weight safety valves*, *lever safety valves*, and *spring-loaded*, or *pop*, *safety valves*, respectively. The dead-weight type is used only on boilers that carry low pressures, such as heating boilers. It consists of a valve attached to a vertical stem on which are placed a number of disk-shaped weights, the valve being held to its seat by the dead-weight of the disks. On vessels that carry high steam pressures, the lever and the pop types are used.

3. Lever Safety Valve.—A form of lever safety valve is shown, partly in section, in Fig. 1. It consists of an iron body *a* with a heavy flange *b* by which it is connected to the boiler, and a flange *c* to which is connected the pipe through which the steam escapes. In the body of the valve is fastened the beveled seat *d*, on which rests the beveled disk *e*. The disk is connected to a stem *f* that passes through the cover *g* and is formed into a yoke *h* at its upper end. The lever *i* (which is broken away at the middle, so that its full length is not shown in the illustration) passes through the yoke *h* and is fulcrumed at one end on the pin *j*, held in a bracket that forms part of the cover *g*. On the other end of the lever is hung a weight *k*, consisting of a cast-iron ball, which may be moved

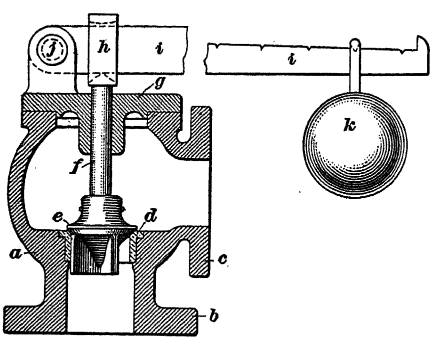


Fig. 1

a stationary boiler generating saturated steam. The valve *a* is held to its seat *b* by the helical spring *c*, which is made of crucible steel. A stem *d* fits into a socket in the valve *a* and carries a collar *e* against which the pressure of the spring is exerted. A similar collar *f* bears on the upper end of the spring. The spring is completely enclosed by the casing *g*, which is part of the casting that forms the cover of the safety valve. The upper collar *f* is adjustable and may be forced down by turning down the screw *h*, this operation putting greater compression on the spring, forcing the valve more firmly to its seat, and thus raising the pressure at which the safety valve will open. Backing out the screw *h*, so as to allow the collar *f* to rise, decreases the compression on the spring and makes the valve open at a lower pressure. After the adjustment has been made, the locknut *i* is tightened so as to hold the screw *h* in a fixed position. The screw *h* is a sleeve that forms a guide for the upper end of the stem *d*.

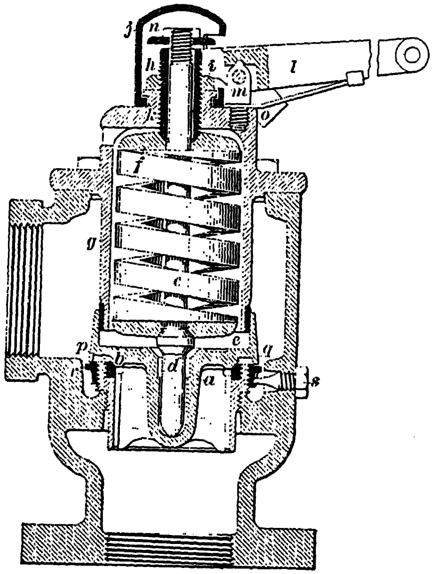


Fig. 2

7. A cap *j*, Fig. 2, is fixed permanently over the upper ends of the valve stem and the adjusting screw by having a lip forced into a groove *k* around the upper end of the valve cover. In the side of the cap is a slot just wide enough to admit the forked end of the lever *l*, which is pivoted on a pin *m*. The forked end fits around the stem *d* beneath the collar *n*, which is screwed to the upper end of the stem. By depressing

increased; that is, the drop of pressure between the opening and the closing of the valve will be made greater. If the ring is turned down, the blow-down will be decreased. A properly adjusted pop safety valve opens sharply and closes promptly, preventing undue loss of steam.

10. A pop safety valve for use on a stationary boiler that generates superheated steam is shown in Fig. 3. Its internal construction is almost exactly like that of the type just described; but the shape of the body is different, and the spring is not enclosed, so that it will not be affected by the high temperature met with in connection with superheated steam. The valve is locked, so as to prevent unauthorized changing of the blow-off pressure; also, it is sealed with a brass tag *a*, on which is stamped the number of pounds of steam that can escape through the valve in an hour, known as the *steam-relieving capacity* of the valve. A safety valve should always be attached to a superheater, and set to blow at a pressure slightly below that at which the safety valve on the boiler will blow. Then, if the engines or turbines are shut down, or the amount of steam used is suddenly decreased, the resultant rise of pressure will cause the safety valve on the superheater to open, and steam will escape by way of the superheater, thus preventing the overheating or burning of the superheater tubes.

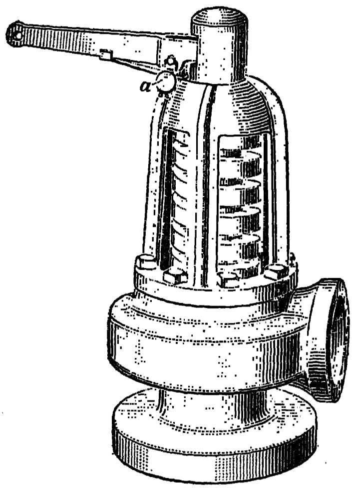


FIG. 3

11. Safety Valves for Marine Boilers.—Safety valves for marine boilers are similar to the pop valves used on stationary boilers and are made with either enclosed or exposed springs, according to the service demanded. They may be mounted

stationary and marine boilers, for they must produce steam very rapidly so as to take care of variable loads. As a result, the locomotive safety valve will frequently be in almost continual action. The feed-water in some localities is very poor, and may therefore cause scale to accumulate around the working parts, thus necessitating frequent cleaning of the safety valve. On account of the hard usage to which the valve is subjected, it must be designed to withstand the frequent blow-off action and must be of a form that readily permits repairs and cleaning operations.

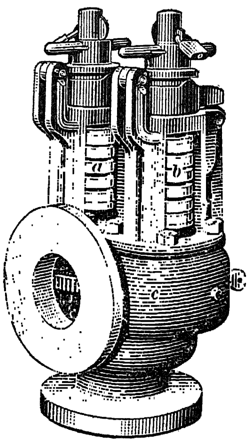


FIG. 5

A locomotive-boiler safety valve with encased spring is illustrated in Fig. 6 (*a*) and (*b*). In construction it is similar to the types of safety valves already described, except that the blow-off is at the top instead of at the side. The valve base *a*, case *b*, adjusting ring *c*, spring washers *d* and *e*, compression screw *f*, and check-nut *g* are made of bronze; and the spring *h* and the spindle *i* are made of steel. View (*b*) shows the arrangement of the steam discharge outlets *j*, which makes it possible for the steam to rise vertically, thus preventing spreading of the escaping steam, which would cloud cab windows and handicap the men operating the locomotive. Locomotive safety valves may also be fitted with mufflers to reduce the noise made by the steam while blowing off. The muffler is made of bronze, in the form of a shell, and is mounted over the body of the safety valve. To allow the escape of the steam, numerous openings are drilled in the muffler.

13. Use and Care of Safety Valves.—The safety valve must be connected directly to the boiler, steam drum, or superheater, so that there is no possible chance of cutting off communication between the boiler and the valve. The cross-

Supervising Inspectors. Safety valves used in stationary power plants in the United States must be made and installed in accordance with the rules of the state in which the boilers are operated. The rules of the American Society of Mechanical Engineers have been adopted by most of the states; therefore, the following data relating to the capacity, installation, and adjustment of the safety valve are taken from the A. S. M. E. Boiler Code.

Safety Valve Requirements

Each boiler having more than either 500 square feet of water-heating surface, or in which the generating capacity exceeds 2,000 pounds per hour, shall have two or more safety valves. (The method of computing the relieving capacity of the safety valves according to the A. S. M. E. requirements is given in Art. **19.**)

The safety-valve capacity for each boiler shall be such that the safety valve or valves will discharge all the steam that can be generated by the boiler without allowing the pressure to rise more than 6 per cent. above the maximum allowable working pressure, or more than 6 per cent. above the highest pressure to which any valve is set.

One or more safety valves on every boiler shall be set at or below the maximum allowable working pressure. The remaining valves may be set within a range of 3 per cent. above the maximum allowable working pressure, but the range of setting of all of the valves on a boiler shall not exceed 10 per cent. of the highest pressure to which any valve is set.

All safety valves shall be so constructed that no shocks detrimental to the valve or to the boiler are produced and so that no failure of any part can obstruct the free and full discharge of steam from the valve. Safety valves may be of the direct spring-loaded pop type, with seat and bearing surface of the disk inclined at any angle between 45° and 90°, inclusive, to the center line of the spindle. The maximum rated capacity of a safety valve shall be determined at a pressure of 3 per cent. in excess of that at which the valve is set to blow and with a blow-down of not more than 4 per cent. of the set pressure, the blow-down to be in no case less than 2 pounds.

Safety valves may be used which give any opening up to the full discharge capacity of the area of the opening of the inlet of the valve, provided the movement of the valve is such as not to induce lifting of the water in the boiler.

Dead-weight and weighted-lever safety valves shall not be used.

Each safety valve ½ inch in size and larger shall be plainly marked by the manufacturer. The marking may be stamped or cast on the casing, or stamped or cast on a plate or plates securely fastened to the casing, and shall contain the following markings:

The safety valve or valves shall be connected to the boiler independent of any other steam connection, and attached as close as possible to the boiler, without any unnecessary intervening pipe or fitting. Every safety valve shall be connected so as to stand in an upright position, with spindle vertical, when possible.

The opening or connection between the boiler and the safety valve shall have at least the area of the valve inlet. No valve of any description shall be placed between the required safety valve or valves and the boiler, nor on the discharge pipe between the safety valve and the atmosphere. When a discharge pipe is used, the cross-sectional area shall not be less than the full area of the valve outlet or of the total of the areas of the valve outlets discharging thereinto, and shall be as short and straight as possible and so arranged as to avoid undue stresses on the valve or valves.

All safety-valve discharges shall be so located or piped as to be carried clear from running boards or platforms. Ample provision for gravity drain shall be made in the discharge pipe, at or near each safety valve, and where water of condensation may collect. Each valve shall have an open gravity drain through the casing below the level of the valve seat. For iron- and steel-bodied valves exceeding 2 inches in size, the drain holes shall be tapped.

If a muffler is used on a safety valve it shall have sufficient outlet area to prevent back pressure from interfering with the proper operation and discharge capacity of the valve. The muffler plates or other devices shall be so constructed as to avoid any possibility of restriction of the steam passages due to deposit.

When a boiler is fitted with two or more safety valves on one connection, this connection to the boiler shall have a cross-sectional area not less than the combined areas of inlet connections of all of the safety valves with which it connects.

Safety valves shall operate without chattering and shall be set and adjusted as follows: To close after blowing down not more than 4 per cent. of the set pressure but not less than 2 pounds in any case. For spring-loaded pop valves operating on pressures up to and including 300 pounds per square inch the blow-down shall not be less than 2 per cent. of the set pressure. To insure guaranteed capacity and satisfactory operation, the blow-down as marked upon the valve shall not be reduced.

To insure the valve being free, each safety valve on boilers with maximum allowable working pressures up to and including 200 pounds per square inch, shall have a substantial lifting device by which the valve disk may be positively lifted from its seat at least $\frac{1}{16}$ inch when there is no pressure on the boiler. For boilers with working pressures above 200 pounds per square inch, the safety-valve lifting device need not provide for lifting the valve disk $\frac{1}{16}$ inch except at such times as there is at least 75 per cent. of the full working pressure on the boiler.

or upward, force, must exceed the external, or downward, force on the valve plus the friction of the mechanism of the valve. If the internal and the external forces on the valve are equal, the valve will be balanced, and an increase of the internal force will cause it to open. A safety valve will not close until the pressure has been reduced somewhat below the pressure at which the valve opened.

The point at which a safety valve will blow off depends on the external force on the valve. To be balanced, or in equilibrium, the external load exerting a downward pressure on the valve must be equal to the internal force exerting an upward pressure on the under face of the valve. Evidently, the upward pressure is equal to the area of the valve multiplied by the pressure per unit of area.

16. Spring-loaded safety valves are always adjusted by comparison with an accurate steam gauge, and this practice is now generally employed when setting the lever safety valve. If it were possible to measure all the parts of the lever safety valve accurately, it might be finally adjusted in accordance with calculations based on such measurements. However, a slight inaccuracy of measurement of one or more of the parts may produce a considerable error, even though the figuring is correctly done. Because of this, calculations regarding the position of the weight on the lever of a lever safety valve are in practice considered as giving only an approximate, or trial, position of the weight on the lever.

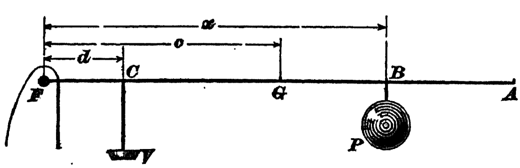


FIG. 7

17. Referring to Fig. 7, the distance from the fulcrum F to the end A of the lever is the over-all length of the lever; this is used only for finding the distance c of the center of gravity G of the lever from the fulcrum F. When the lever is straight and of the same width and thickness throughout, the

SOLUTION.—The area of the valve is $A=4^2\times.7854$. As the lever is straight, the distance c from the fulcrum to the center of gravity is taken as one-half its length, or $\frac{44}{2}$. Apply formula **1**, and

$$P=\frac{120\times40+20\times\frac{44}{2}+10\times4}{4^2\times.7854\times4}=105 \text{ lb. per sq. in., nearly.}\quad \text{Ans.}$$

EXAMPLE 2.—With a safety valve having the dimensions given in example 1, what weight is necessary to have the valve about to blow off at a steam pressure of 100 pounds per square inch?

SOLUTION.—Apply formula **2**, and

$$W=\frac{4^2\times.7854\times100\times4-(20\times\frac{44}{2}+10\times4)}{40}=113.66 \text{ lb.}\quad \text{Ans.}$$

EXAMPLE 3.—A safety valve has an area of 11 square inches; the distance from the center line of the valve to the fulcrum is 3 inches; the steam pressure, 40 pounds per square inch; the weight weighs 50 pounds; the lever is straight and parallel, 32 inches long, and weighs 15 pounds; the valve and stem weigh 6 pounds. How far from the fulcrum must the weight be placed?

SOLUTION.—Apply formula **3**, and

$$L=\frac{11\times40\times3-(15\times\frac{32}{2}+6\times3)}{50}=21.24 \text{ in.}\quad \text{Ans.}$$

A candidate for American marine engineer's license should thoroughly familiarize himself with the calculations pertaining to a lever safety valve, as a candidate for a marine engineer's license must be rejected by the examining inspectors if he fails to solve safety-valve problems similar to those given in the preceding examples.

18. Spring Safety-Valve Calculations.—The question often arises as to the pressure for which a safety-valve steel spring is intended. When made with 13 complete turns, the standard prescribed, the question can be answered by an application of the rule of the Board of Trade, Great Britain, governing this problem.

Rule.—*To find the steam pressure for which a spring is intended, cube the diameter, in inches, of the wire, if round, or the side of square, if square, and multiply by 8,000 for round wire and 11,000 for square wire. Divide the product by the product of the diameter of the spring, in inches, measured from center to center of the wire, and the area of the safety valve.*

heat units required to convert a pound of feedwater into steam. The value of C is found by making a test to determine

TABLE I

HEATING VALUES OF VARIOUS FUELS

(A. S. M. E. Boiler Code)

Fuel	Heating Value	
	B. t. u. per Pound	B. t. u. per Cubic Foot
Semi-bituminous coal	14,500	
Anthracite	13,700	
Screenings	12,500	
Coke	13,500	
Wood, hard or soft, kiln-dried	7,700	
Wood, hard or soft, air-dried	6,200	
Wood shavings	6,400	
Peat, air-dried, 25 per cent. moisture	7,500	
Lignite	10,000	
Kerosene	20,000	
Petroleum, crude oil, Pennsylvania	20,700	
Petroleum, crude oil, Texas	18,500	
Natural gas		960
Blast-furnace gas		100
Producer gas		150
Water gas, uncarbureted		290

the greatest amount of fuel that can be burned per hour, and the heating value H of the fuel may be found from Table I.

20. After the value of W, the weight of steam generated per hour, has been found by the formula of the preceding article, the size of safety valve required may be determined by use of Table II. The table gives the discharge capacities of safety valves from $\frac{1}{2}$ inch to 8 inches in diameter at pressures ranging from 15 to 250 pounds per square inch, gauge.

EXAMPLE 1.—The amount of fuel burned under a boiler during the period of maximum forcing is 1,140 pounds of semi-bituminous coal per hour. If the boiler pressure, as shown by the steam gauge, is 125 pounds per square inch, find the size of safety valve required.

SOLUTION.—Apply the formula of Art. **19**. From Table I, $H=14{,}500$ B. t. u.; and $C=1{,}140$ lb. Then,

$$W=\frac{.75\times1{,}140\times14{,}500}{1{,}100}=11{,}270 \text{ lb. per hr.}$$

On referring to Table II, it is discovered that, at a pressure of 125 lb. per sq. in., the largest size of valve, 6 in. in diameter, has a discharge capacity of 13,711 lb. per hr., but, two valves should be used on a boiler. A 4-in. valve will discharge 6,128 lb. per hr. at 125 lb. per sq. in., and two such valves will discharge 12,256 lb. per hr., which is slightly more than the value of W. Hence, two 4-in. valves will be used. Ans.

EXAMPLE 2.—A boiler carrying 250 pounds pressure burns 1,000 pounds of Pennsylvania crude oil per hour when forced to its maximum. What size of safety valve is required?

SOLUTION.—Apply the formula of Art. **19**. From Table I, $H=20{,}700$ B. t. u. for Pennsylvania crude oil; and $C=1{,}000$ lb. Then,

$$W=\frac{.75\times1{,}000\times20{,}700}{1{,}100}=14{,}114 \text{ lb. per hr.}$$

Table II shows that two $3\frac{1}{2}$-in. valves will furnish the necessary capacity. Ans.

FUSIBLE PLUGS

21. Purpose of Fusible Plugs.—A fusible plug is a device that is screwed into the crown sheet, tube-sheet, or water leg of a boiler to protect the boiler in case of low water. It consists of a brass or bronze shell cored out and filled with pure tin, which has a melting point a trifle higher than the temperature of the water in the boiler. As long as the plug is covered with water, it transmits the heat to the water rapidly. When the crown sheet or other boiler surface into which it is screwed is exposed directly to the heat without being covered with water, the fusible part of the plug melts quickly, and steam and water are blown through the cored opening of the plug, thus giving warning of low water. The reliability of the plug depends on the melting or fusing temperature of the tin filling at the time it should operate. The presence of relatively small amounts of impurities in the filling may cause a change in its composition and possibly render it useless. Correct methods of manufacture and the use of the best grade of filling material are the means of insuring reliable plugs.

and shall be renewed once each year. The least diameter of fusible metal shall be not less than $\frac{1}{2}$ inch, except for maximum allowable working pressures of over 175 pounds per square inch, or when it is necessary to place a fusible plug in a tube, in which case the least diameter of the fusible metal shall be not less than $\frac{3}{8}$ inch.

The use of fusible plugs is not advisable in boilers that are to be operated at working pressures exceeding 225 pounds per square inch. If a fusible plug is inserted in a tube, the tube wall must be not less than .22 inch thick, or thick enough to give four threads.

24. Location of Fusible Plugs.—In horizontal return-tubular boilers, the plug is usually placed in the back head, not less than 2 inches above the top row of tubes, measuring from the top of the tube to the center of the plug. In firebox boilers of the locomotive type, the plug is screwed into the highest point of the crown sheet. In Scotch boilers, the plug is screwed into the top plate of the combustion chamber. In vertical fire-tube boilers, the plug is screwed into one of the outside tubes, and arranged so that it is at least one-third the length of the tube above the lower tube-sheet. In water-tube boilers of the Heine type, it is screwed into the shell of the steam drum, not less than 6 inches above the bottom of the drum. In general, the plug should be so located that it will be in the path of the hot gases and arranged so that it is at the highest point of the boiler, where low water would first become evident.

WATER-LEVEL INDICATORS

25. High- and Low-Water Alarms.—It is important to maintain proper water level in a boiler, so as to safeguard life and valuable equipment, as well as to insure economy in the burning of fuel. Low water may mean burned-out tubes, or crown sheets, which might lead to boiler explosions. An excessively high water level may cause priming, and flood the steam line leading to the pumps, engines, or turbines, so that damage will result to this equipment.

water falls in the column to a low level, the weight of the float *a*, acting through the vertical stem *c*, pulls the lever *b* down and thus opens the valve *d*, allowing steam to pass and sound the whistle *e*. When the water level rises sufficiently the float rises until the stop *f* engages the lever *b*, pushing it up. As this lever is double-acting, it operates the valve *d* by either an upward or a downward motion. The stop *f* is adjustable and can be set in any desired position on the rod *c*. The proper action of the signal can be tested by opening the drain valve attached at *g*, which will drain the water and allow the float to fall and sound the whistle. Gauge-cocks *h* and a gauge glass *i* are connected to the body of the water column, as shown. The device is connected at *j* with the steam space of the boiler and at *k* with the water space.

28. Gauge-Cocks.—A gauge-cock is a simple cock or valve attached either directly to the boiler, or, preferably, to a water column, for the purpose of testing the level of the water in the boiler. Three gauge-cocks are generally employed. The lowest is placed at the lowest level that the water may safely attain, and the uppermost at the highest desirable level. The third cock is placed midway between the other two. On opening a cock above the water level, steam will issue forth, and on opening one below the water level, water will appear. Hence, the level may be easily located by opening the cocks in succession.

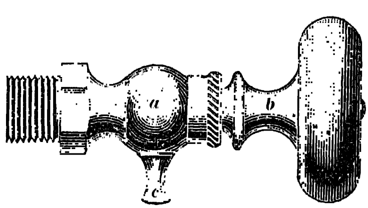


FIG. 11

29. The gauge-cock most commonly used is of the compression type. Such a cock, with a wooden hand wheel, is shown in Fig. 11. It consists of a brass body *a* having a threaded shank for attaching it to the boiler or water column. The seat within the body is closed by the end of the threaded valve stem *b*. The steam or water issues from the nozzle *c* when the cock is opened. Compression gauge-cocks can be obtained with a lever handle in the form of a crank. Such

32. Automatic Safety Water Gauges.—To prevent loss of steam and water, and to obviate the danger of scalding the workman who tries to close the valves, it is desirable to have water gauges that will automatically shut off communication with the boiler whenever the gauge glass breaks. There

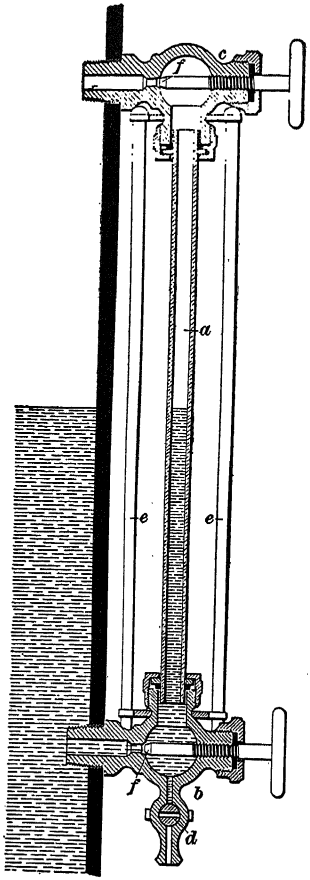
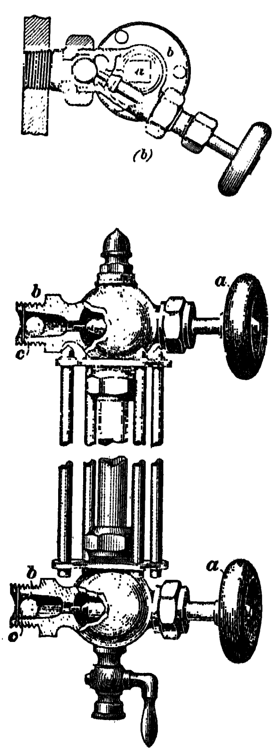


FIG. 13



(a)

FIG. 14

are many designs of such valves on the market. Fig. 14 (*a*) is a typical automatic pattern with hand-control valves *a*. A ball *b* is placed within the shank of each fitting, and is prevented from falling out by a brass pin *c*. Should the gauge

as shown in Fig. 15 (*a*) and (*b*), may be used. The balls are arranged as shown at *a* in the cross-sectional view (*a*) and work on the same principle as in Fig. 14, in case of glass breakage. The levers *b*, Fig. 15, are operated by chains *c* and the valves are closed and opened by pulling the chains.

33. Water Column.—A common form of water column is shown in Fig. 16. It consists of a hexagonal cast-iron standpipe *a* tapped at the top and the bottom for pipe connections to the boiler. Tapped bosses are provided, which receive the threaded shanks of the gauge-glass fittings *b* and the gauge-cocks *c*. Each maker has his own style of standpipe, the different makes varying chiefly in the ornamentation. The steam gauge is frequently mounted on top of the water column.

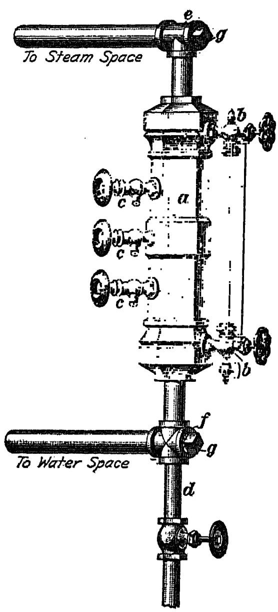


FIG. 16

In certain States, it is not allowable to place valves in the piping between the water column and the boiler, because of the danger that such valves may be closed and thus cause incorrect indication of the water level, with the possibility of serious consequences. Yet it is convenient to have shut-off valves, to avoid the necessity of closing down the boiler in case of accident to the water column. If such valves are installed, the fireman should make sure that they are fully open when the boiler is in operation. The pipe connections to the water column should not be less than $1\frac{1}{4}$ inches in diameter.

34. Water-Column Connections.—The connection to the boiler should be made with a **T** on the top, as at *e*, Fig. 16, and a cross *f* on the bottom, with the unused openings plugged with brass plugs *g*. If the connections are made in this manner,

for the installation of gauge glasses, gauge-cocks, and water columns:

Each boiler shall have at least one water-gauge glass, the lowest visible part of which shall be not less than 2 inches above the lowest permissible water level. The lowest permissible water level for various classes of boilers shall be the location for the fusible plug.

Automatic shut-off valves on water gauges, if permitted to be used, shall conform to the following requirements:

(*a*) Check-valves in upper and lower fittings must be of the solid non-ferrous ball type to avoid corrosion and the necessity for guides.

(*b*) Ball check-valves in upper and lower fittings must open by gravity, and the lower check-valve must rise vertically to its seat.

(*c*) The check balls must not be smaller than $\frac{1}{2}$ inch in diameter, and the diameter of the circle of contact with the seat must not be greater than two-thirds of the diameter of the check ball. The space around each ball must not be less than $\frac{1}{8}$ inch, and the travel movement from the normal resting place to the seat must not be less than $\frac{1}{4}$ inch.

(*d*) The ball seat in the upper fitting must be a flat seat with either a square or a hexagonal opening, or otherwise arranged so that the steam passage can never be completely closed by this valve.

(*e*) The shut-off valve in the upper fitting must have a projection which holds the ball at least $\frac{1}{4}$ inch away from its seat when the shut-off valve is closed.

(*f*) The balls must be accessible for inspection. Means must be provided for removal and inspection of the lower ball check-valve, while the boiler is under steam pressure.

When shut-offs are used on the connections to a water column, they shall be either outside-screw and yoke-type gate valves or stop-cocks with levers permanently fastened thereto and marked in line with their passage, and such valves or cocks shall be locked or sealed open.

Each boiler shall have three or more gauge-cocks, located within the range of the visible length of the water glass, except when such boiler has two water glasses with independent connections to the boiler and located on the same horizontal line and not less than 2 feet apart.

No outlet connections, except for damper regulator, feed-water regulator, drains, or steam gauges, shall be placed on the pipes connecting a water column to a boiler.

PRESSURE GAUGES

37. Steam Gauge.—The steam gauge, the face *a* of which is shown in Fig. 18, indicates the pressure of the steam contained in the boiler. The most common form is the *Bourdon pressure gauge*, the distinguishing feature of which is a bent elliptical

The single-tube steam gauge, shown in Fig. 20, consists of a tube *a*, the free end of which is connected to a lever *b* attached to a toothed sector *c* that moves a small pinion on the pointer shaft *d*. Lost motion is prevented by the action of a small hair-spring *e*, which is also used in steam gauges of the double-tube type.

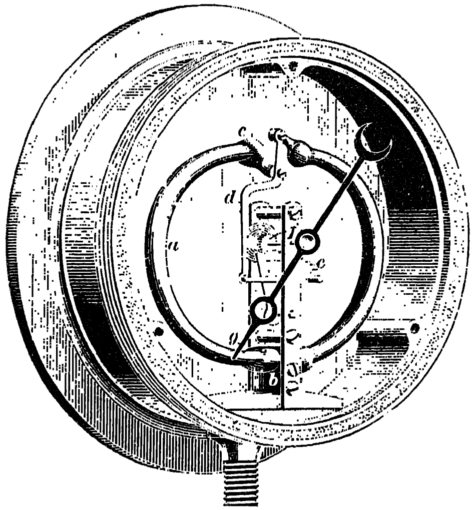


FIG. 19

Pressure gauges for indicating steam pressure are graduated to show the pressure above that of the atmosphere, in pounds per square inch, wherever the English system of weights and measures is used.

39. Steam-Gauge Siphons.—A steam gauge must be connected to the boiler in such a manner that it will not be injured by heat nor indicate the pressure incorrectly. To prevent injury from the heat of the steam, a siphon may be used to connect the steam gauge to the steam space of the boiler. The siphon may be arranged as shown in Fig. 21 (*a*) and (*b*), or as in Fig. 22. Within a short time after the steam gauge is

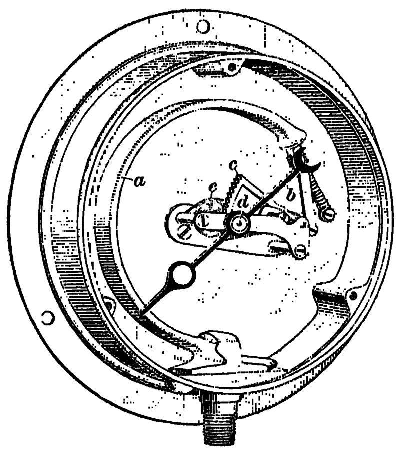


FIG. 20

fact that the tube loses its elasticity and takes a permanent set. In this case the gauge will indicate a pressure higher than the actual pressure in the boiler. This can usually be discovered by the failure of the pointer to return to the zero mark when there is no pressure in the boiler. If the pressure apparently indicated when there is no pressure is subtracted from the pressure indicated when the boiler is under steam, the correct pressure will be given approximately. However, when a gauge shows a wrong pressure, a new one should be immediately substituted and the old one discarded or sent to the maker for repair.

When inspecting boilers, the inspectors of boiler-insurance companies or municipal boiler inspectors usually test all steam gauges in the plant by comparison with an accurate test gauge. The gauge to be tested and the test gauge are both attached to a vessel in which the pressure is raised by means of a small force pump, and the readings of the two gauges at different pressures are compared.

41. The safety valve can be checked by means of the steam gauge when the latter is known to be accurate. Conversely, when the safety valve is known to be set correctly, the steam gauge can be checked for the blow-off pressure by watching its indication when the valve just blows off. If a steam gauge shows an error of more than 5 pounds, it will be condemned by most boiler inspectors. The steam gauge should be taken off periodically and the connecting pipe cleared by blowing steam through it. When the gauge is off, care should be taken to see that the hole in the nipple is perfectly clear.

Good practice demands that a steam gauge should be attached to each boiler, when more than one boiler is used. In some regions, however, it is not uncommon to see one steam gauge do duty for a whole battery of boilers. Such an arrangement has nothing but cheapness to recommend it and is severely condemned by engineers and insurance companies.

42. When the boiler supplies steam to a steam engine, it sometimes happens that, when the engine is running, the pointer of the steam gauge vibrates so much that the pressure

The dial of the steam gauge shall be graduated to approximately double the pressure at which the boiler will operate, but in no case to less than $1\frac{1}{2}$ times the maximum allowable working pressure on the boiler.

Each boiler shall be provided with a $\frac{1}{4}$-inch pipe size valved connection for the exclusive purpose of attaching a test gauge when the boiler is in service, so that the accuracy of the boiler steam gauge can be ascertained.

SUPERHEATERS

45. Purpose of Superheating.—Steam in contact with the water in a boiler has the same temperature as the water and is known as saturated steam. Additional water may be taken up by the steam through priming of the boiler or from the movement of the boiler, as in marine, portable, and locomotive boilers. Moisture also arises from condensation of the steam. Large heat losses result from the use of wet steam for power purposes, and there are other disadvantages in the effect of such steam on turbines, engines, etc. In turbines, water in the rapidly moving steam erodes, or wears away, the blades, and increases the amount of steam used. The same conditions arise in reciprocating engines, and there is a possibility of damaging the cylinder heads and the stuffingboxes around piston rods and valve stems.

46. The demand for greater economy in the performance of steam engines has led to the development of the superheater, by means of which the steam may be superheated to a moderate degree so that it will contain more heat and therefore do more work than would the same weight of saturated steam, and thus insure increased engine economy. In order to superheat the steam, it must pass from the boiler into a separate compartment and have more heat applied to it. This may be done with a separate furnace or by using a coil of pipe within the boiler setting itself; or, the superheater may be arranged in the smokebox of a locomotive boiler, or in the uptake leading to the stack in other boiler installations.

47. Wrought-Iron Superheater.—One form of superheater, as arranged in connection with a water-tube boiler, is shown in Fig. 23 (*a*) and (*b*). It consists of a number of bent wrought-

nected by means of two pipes *e*, *e'*, to the steam outlet *f* on top of the boiler. The steam is drawn from the dry pipe through the pipes *c*, *c'* to the upper header *b*, thence through the superheater tubes *a* to the lower header *b'*, and up the external pipes *e*, *e'*, to the steam outlet *f*. The lower header *b'* is connected to the water space of the boiler by means of the pipes *g* and *h*, fitted with valves *i* and *j* for the purpose of filling the superheater with water when not in use, as is the case when getting up steam or when the engine is not running. To put

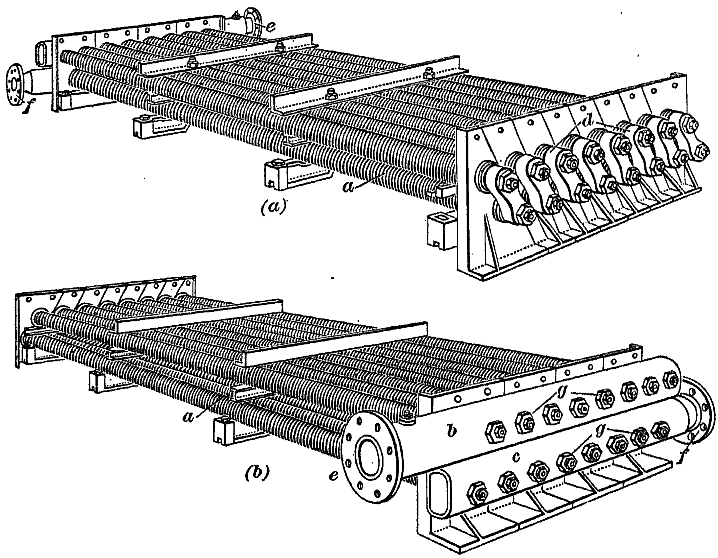


FIG. 24

the superheater into service, the water is drained from it by means of the three-way valve *i*. Not all superheaters have provision made for flooding while steam is being raised. In many cases a valve on the superheater is opened, allowing air and steam to escape from the superheater until full pressure on the boiler is reached, when the valve is closed and the superheater is cut into service.

48. Foster Superheater.—The Foster superheater, two views of which are shown in Fig. 24 (*a*) and (*b*), consists of a

a large amount of surface to be exposed to the hot gases, and at the same time to take care of the expansion and contraction. Saturated steam from the boiler enters the header *b*, which is closed at the end *d*, and flows through the banks of piping *a*, wherein it is superheated. It then passes out of the tubes *a* into the header *c*, which lies behind the header *b*, and which is also closed at one end. The flange *e* on the header *b* forms a connection for the installation of the safety valve.

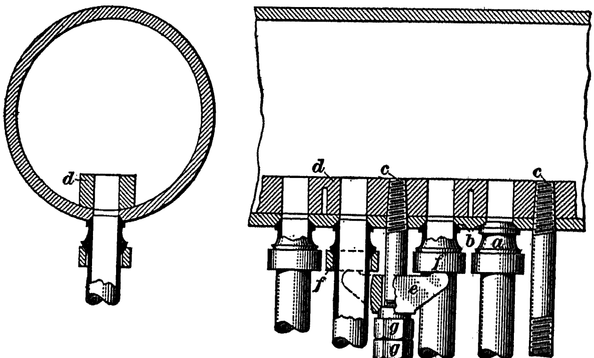


FIG. 27

50. The ends of the tubes are connected to the headers by metal-to-metal joints, as shown in the sectional view, Fig. 27. The end *a* of each tube is formed by a special forging process and is then ground to an angle of 45° to fit the conical seat in the header, as shown at *b*. Between each pair of tubes is a stud *c* that passes through the wall of the header into a reinforcing strip *d*. A two-armed clamp *e* is slipped over the stud, and its ends bear against the collars *f* on the tubes. When the clamp is forced against the collars by screwing up the nuts *g* on the stud, the ends of the tubes are held tightly in the conical seats in the header. This construction enables the tubes to be removed or replaced with little labor or loss of time.

as much as one-tenth larger or smaller than that indicated. In boiler, plate, and tank work, various forms of rivets are used, and their names are derived from the shapes of their heads. Of the several forms shown in the illustration, those in (*b*),

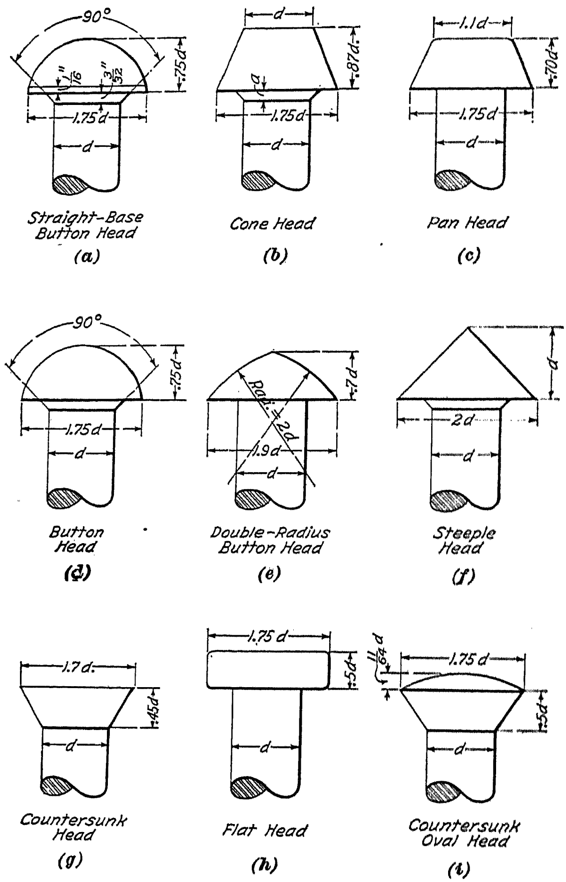


FIG. 1

(*c*), (*d*), (*e*), and (*g*) are most commonly used in boiler construction. The cone-head rivet is slightly tapered under the head, the depth *a* of the tapered part being $\frac{1}{32}$ inch for rivets from $\frac{1}{2}$ inch to 1 inch in diameter and $\frac{1}{16}$ inch for rivets greater than 1 inch in diameter. The outer edge of the rivet

but very rapid blows, with an *air hammer*, or *pneumatic hammer*, the process is called *pneumatic riveting*. If the head is formed by squeezing, or upsetting, the metal of the neck under high pressure in a machine, the process is called *machine riveting;* and if the machine is operated by hydraulic pressure, the process is called *hydraulic riveting*, or *bull riveting*.

5. For boiler work in general, machine riveting has important advantages over hand riveting, and it is now employed wherever possible. The advantages are as follows: (*a*) A tighter joint can be made for the reason that the plates that are being riveted can be held together with greater force while the second rivet head is being formed. (*b*) The holes in the plates can be filled better, because the shank is made to spread out by the pressure applied to upset the rivet and to form the head. (*c*) It is faster and cheaper, if many rivets are to be driven.

FORMS OF RIVETED JOINTS

6. Terms Used in Riveted Work.—If a joint is formed by having the edges of two plates overlapped and joined by one or more rows of rivets, it is called a *lap joint*. If the plates are placed edge to edge and the junction or seam is covered with a narrow strip of boiler plate, called a *strap*, on either one or both sides of the plate, and the whole is riveted together, the joint is called a *butt joint*. The strap is also known as a *cover-plate*, a *welt*, or a *butt strap*. The terms *seam* and *joint* mean the same when applied to riveted connections.

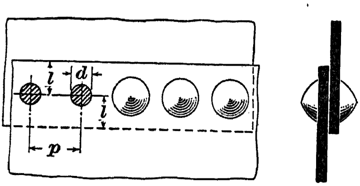
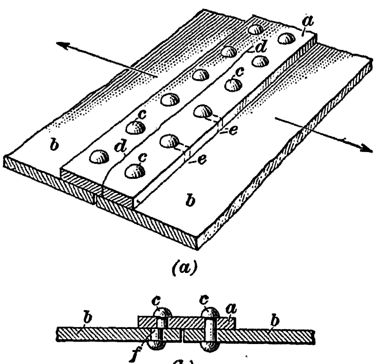


FIG. 3

Riveted joints are also classified, according to the number of rows of rivets in the seam, as *single-riveted, double-riveted, triple-riveted,* and *quadruple-riveted joints,* and from the arrangement of the rivets in the joint as *staggered-riveted* and *chain-riveted joints*. A single-riveted lap joint is shown in Fig. 3. The distance between rivet centers, measured in the direction

Triple-riveted and quadruple-riveted lap joints are now seldom used in boiler work. Formerly such joints were used for longitudinal seams, but owing to the offset produced by overlapping the plate, difficulty arose in obtaining a true cylindrical shell. Another objection to such seams is that when the shell is under pressure, a bending action arises in the joint, which produces crystallized metal between the rivets. A correctly designed butt joint is superior to the lap joint in regard to strength and by its use the shell can be rolled to a true cylindrical form.

8. Single-Riveted Single-Strap Butt Joint.—A single-riveted butt joint with a single cover-plate *a* is illustrated in Fig. 6 (*a*) and (*b*). The ends of the boiler shell *b* are butted against each other, and in order to have the edges straight and parallel with each other they are machined on a plate planer. It will be seen that the joint has two rows of rivets *c* and yet is called a single-riveted butt joint. This follows from the fact that the separation of one plate from the other is opposed by only one row of rivets. Thus, if the plate is stronger than the rivets, the plates *b* can be separated only by shearing off the rivets. The pull on the joint, as shown by the arrows in (*a*), tends to break or tear the butt strap along the line *d d*, to crush or shear the metal in front of the rivets, as indicated by the dotted lines *e*, and to shear the rivets as shown at *f* in (*b*). Rivets driven through the plate and the butt strap and acted on by the pressure are in single shear, as the resistance of the rivet to shearing action is that of the sectional area of each rivet. Butt joints with single butt straps may be double-riveted, triple-riveted, etc., and the rivet arrangement may be chain or staggered.



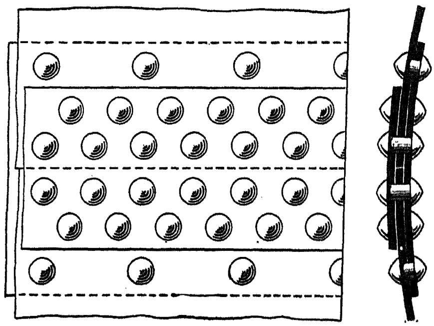
(*a*)

(*b*)

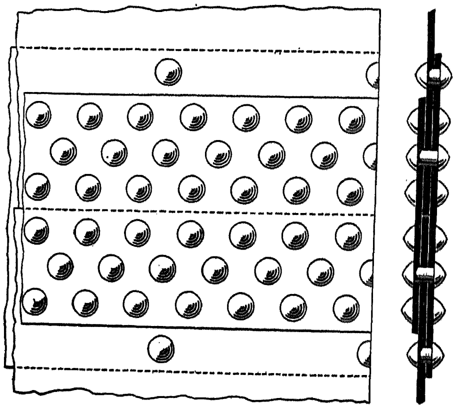
FIG. 6

usually staggered. The pitch of the rivets in the outer rows, which are in single shear, is double the pitch of the rivets in the inner rows.

10. Butt Joints With Straps of Equal Widths.—A triple-riveted double-strap butt joint with chain riveting is shown in



(*a*)

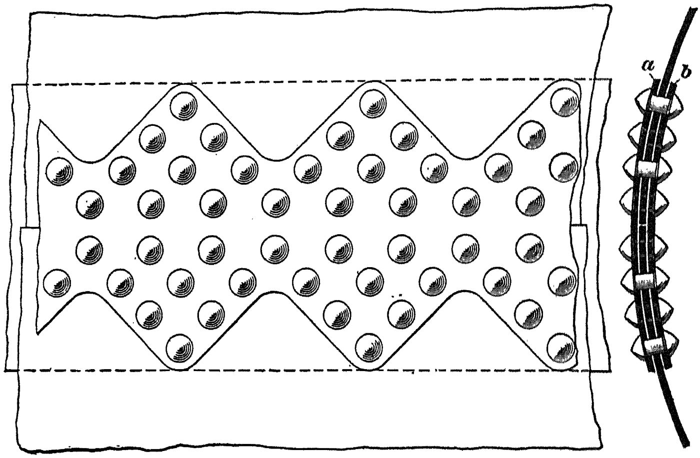


(*b*)

FIG. 8

Fig. 9 (*a*) and the same type of joint with staggered riveting in (*b*). The inner and the outer butt straps are of the same width. On each side of the center line of the seam, indicated by the dotted line, there are three rows of rivets. The rivets

plate. By calking, is meant the forcing of the edge of the plate or rivet into close contact with the plate, so as to produce a steam-tight joint. It should be observed that the rivets in a



(a) (b)

FIG. 10

double-strap butt joint are in double shear; that is, it is necessary to shear each one along two sections to tear the joint apart by shearing off the rivets.

ARRANGEMENTS OF RIVETED JOINTS

11. Location of Longitudinal Seams in Shell Boilers. Owing to the high furnace temperatures, the eroding action of the fuel gases, and the number of overlaps in the plates, it is customary to locate the longitudinal seams of shell boilers as far as possible from the fire. Shell boilers of the horizontal return-tubular type usually have two or more sections, or *courses,* with only one longitudinal seam to the course. The longitudinal seams are so arranged that they *break joints,* or alternate, as shown at *a* and *a′*, Fig. 11; that is, the longitudinal seams in adjacent courses are not in one line, but one seam is to the right and the other to the left of the center. Each

In a vertical tubular boiler, the longitudinal (vertical) seam, if the boiler has only one course, may be located wherever convenient, provided it is clear of the fire-door opening. If the boiler has two or more courses, the longitudinal seams should break, or alternate.

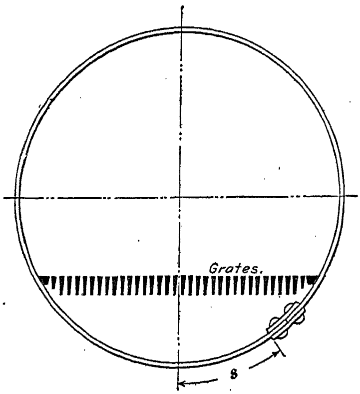


FIG. 12

13. Connecting Longitudinal Lap Joints at Girth Seam.—If plates lap together at the girth seams in boilers having longitudinal lap joints, the inner end *a*, Fig. 13, of the plate must be hammered out thin or scarfed, as it is commonly called, at the corner *b*. The outer end *c* of the plate is bent circular so as to fit the scarfed corner of *a*. If the lap joint is double zigzag-riveted, as shown, it is customary to make the pitch of all the rivets in the outer row uniform; in the inner row, the distance *d* from the rivet in the girth seam to the first rivet of the longitudinal seam will then be equal to 1½ times the pitch.

14. Connecting Single-Strap Butt Joint and Girth Seam. In the case of butt joints having single cover-plates, the junction of the longitudinal seam and the girth seam is made as shown in Fig. 14. The larger shell course *a* overlaps the smaller course *b*, thus forming the girth seam *c*. The butt

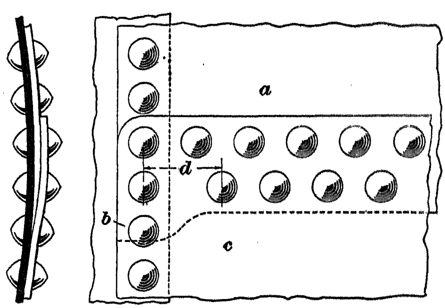


FIG. 13

strap *d* extends to the outer overlapping edge of the larger course *a* and the rivets *e* of the girth seam pass through the shell plates *a* and *b* and the strap *d*. In staggered riveting,

The connection of the girth seam *f* and the longitudinal seam is made by extending the inner butt strap *e* to the edge of the course *a*. The external strap *d* is either made straight and butted against the plate *g* or else it is scarfed and placed under the larger course *g*. In the former case, sufficient space must

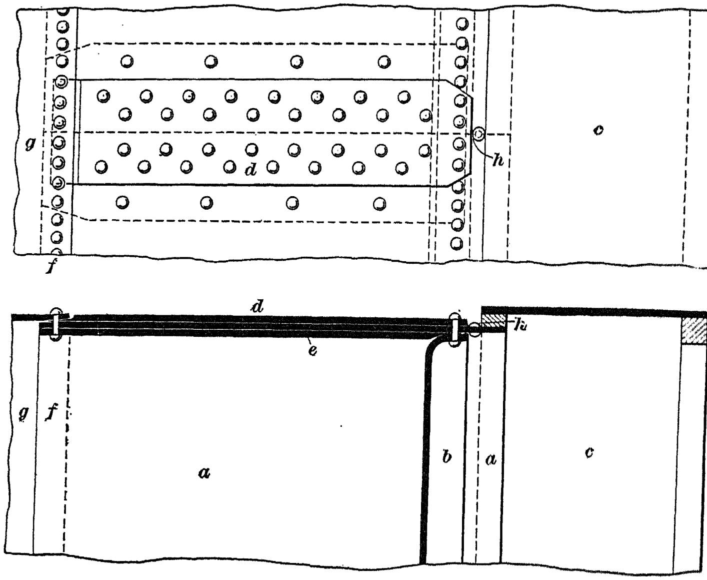


FIG. 16

be allowed between the shell and the butt strap for calking the seam. To prevent leakage at the junction of the butt joint and the smokebox, a *stop-rivet* *h* is used. It is usually a plug $\frac{3}{4}$ or $\frac{7}{8}$ inch in diameter, threaded and screwed tightly into the sheet *a*, after which both ends are formed into heads and then calked.

17. Connecting Double-Strap Butt Joint and Girth Seam. In a horizontal return-tubular boiler having three courses, as in Fig. 17 (*a*) and (*b*), the middle course *a* is slightly smaller in diameter and fits inside the two end courses *b* and *c*. The outer butt strap *d* of the longitudinal seam of the small course is scarfed at both ends and placed under the plate of the larger

courses *b* and *c* as shown at *e* in the sectional view (*b*). The inner butt strap *f* is not scarfed and extends the full length of the middle course *a*.

The arrangement of the girth seam and the longitudinal seams in the end courses is illustrated in Fig. 18 (*a*) and (*b*). The outer butt strap *a* is made equal to the length of the end course *b*. The inner butt-strap *c* is usually scarfed at both ends, as indicated at *d*. At one end it is passed over the flange of the tube-sheet and at the other end over the middle course *c*

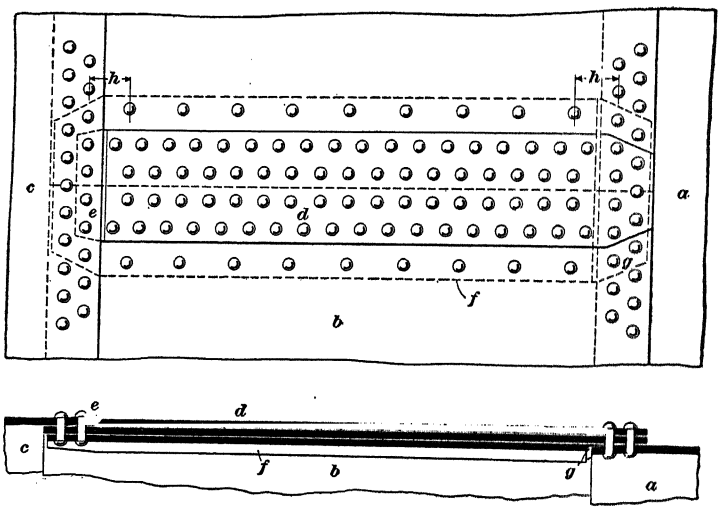


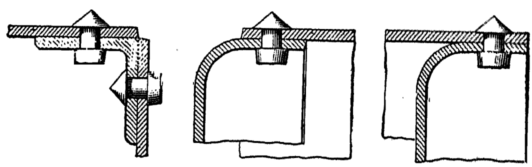
FIG. 19

at the girth seam *f*. In the return-tubular boiler, the heads or tube-sheets usually have their flanges placed inside the boiler; but there are types having the shell forming the smokebox as shown in Fig. 16, and in such a case the head at the smokebox end is backed in.

18. Seam Connections of Shells of Locomotive Boilers. An approved arrangement of the circumferential and longitudinal seams of the first, second, and third courses of a locomotive boiler is shown in Fig. 19. The circumferential seams are double-riveted and the longitudinal seams have double butt

19. Arrangement of Smokebox Joints.—In the locomotive type of boiler, which always has a smokebox, and in the horizontal return-tubular boiler, which may have one, the smokebox may be a separate course, or the first course may be extended, serving for both the smokebox and the first course. The first mentioned construction is customary for large boilers, and the second one for small boilers. In boilers having double-riveted longitudinal lap joints and the first course and smokebox made of one sheet, there is no need of double-riveting the longitudinal joint of the smokebox, as it is not subject to pressure. The usual method of arranging the seams is shown in Fig. 20 (*a*). In this illustration, part of the first course is shown at *a*; the smokebox end of the sheet, at *b*; and the front flue sheet, or round head, which is backed in, at *c*. Because the smokebox is single-riveted while the shell sheet is double-riveted, the shell sheet is cut away as shown. The inside of the shell plate is scarfed at *d* in order that a tight joint can be made between it and the head *c*.

20. In a boiler having the first course and the smokebox made of one sheet and a longitudinal double-riveted double-strap butt joint, it is the usual practice to scarf the inner butt strap *a*, Fig. 20 (*b*), and insert the scarfed end between the flanged head *b* and the shell sheet *c*. The outer butt strap *d* is made long enough to reach to the end of the smokebox and is single-riveted, as shown. A stop-rivet *e* is placed at the edge of the flange of the front head.



(*a*) (*b*) (*c*)

FIG. 21

21. Methods of Making Angular Connections.—There are various ways of making angular connections in structural and boiler work. Some of the methods are illustrated in Fig. 21. For structural work, such as tanks, breechings, and bases for

tively thin or the water space at the bottom very large, because the thickness of the sheet will be reduced considerably by the operation of flanging.

23. In locomotive-type boilers, the fire-door hole is usually constructed as shown in Fig. 24. The door sheet *a* of the furnace is flanged outwards and the back head *b* is flanged inwards,

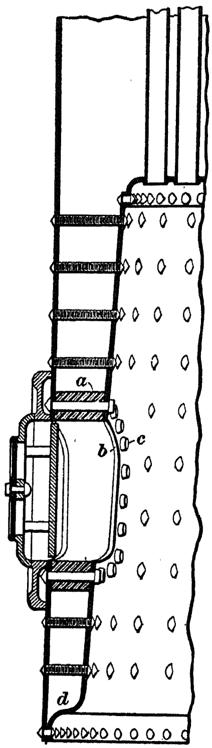


FIG. 23

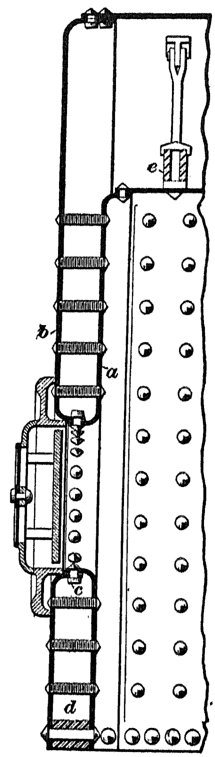


FIG. 24

the two flanges being united by a row of rivets *c*. The bottom of the water leg must not be closed by flanging the furnace sheets, as this would prevent the holding on and driving of the rivets *c*. It is closed by placing a mud-ring *d* between the furnace sheets and the outer plates and securing the ring to the sheets with rivets. The mud-ring is usually made of wrought iron, although cast-steel rings are extensively used.

26. Connecting Sheets to Mud-Rings.—In large locomotive-type boilers the bottom of the water leg is closed by a wrought-iron or steel mud-ring. In modern practice, the ring is made of sufficient depth to project about $\frac{1}{2}$ inch below the lower edge *a*, Fig. 27, of the furnace and water-leg sheets, thus permitting the edges to be calked from the sides. If the mud-ring does not project below the lower edges of the sheets, leaky calking edges are calked with great difficulty, especially if the boiler is standing on a frame or foundation. To prevent the mud-ring from cracking at the corners, it is good practice to provide a boss *b* at each corner. The extra metal in the boss will counteract the weakening effect of the holes drilled for the *corner bolts,* which are bolts used to fasten the sheets to

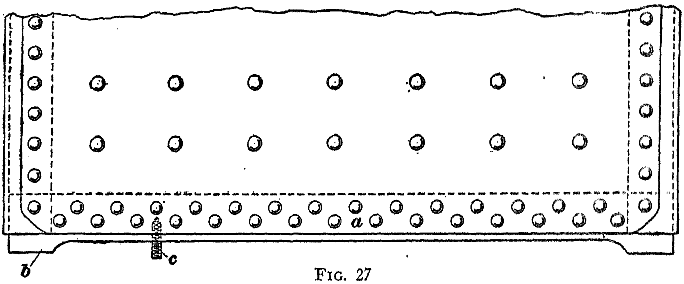


FIG. 27

the mud-ring at the corners. Mud-rings for boilers carrying medium pressures are generally single-riveted; for high-pressure boilers, double zigzag riveting is considered good practice.

27. When studs are to be screwed into mud-rings for attaching an ash-pan or for a similar purpose, the studs must be so located as to clear the rivets. In a single-riveted mud-ring, the studs should be placed midway between rivets; in a double-riveted mud-ring, they should be placed directly beneath a rivet of the upper row, as shown at *c*, Fig. 27.

28. In modern practice, mud-rings are machined both inside and outside, thus eliminating the expensive and difficult work required to make the sheets fit metal to metal over an unfinished or rough mud-ring. The corners of mud-rings should be shaped as illustrated in the plan view, Fig. 28 (*a*). This con-

for the corner bolts *e* are drilled through the sheets *a* and *c* into the mud-ring. The holes are then tapped, and enlarged or countersunk in the plates *a* and *c*, so that the heads of the corner bolts will be similar to oval countersunk rivet heads. Instead of using corner bolts with oval heads, some mechanics thread a rod and screw it into the mud-ring. This rod is then cut off, sufficient material being left to form a head, and the projecting ends are riveted over, thus filling the countersunk holes in the plates *a* and *c*. The edges of the bolt heads are always calked down to the sheet. In the illustration, corner bolts are used at the corner, but very often rivets are used at this point.

30. In Fig. 30 (*a*) is illustrated a longitudinal section and in (*b*) a cross-section of a firebox corner, showing the con-

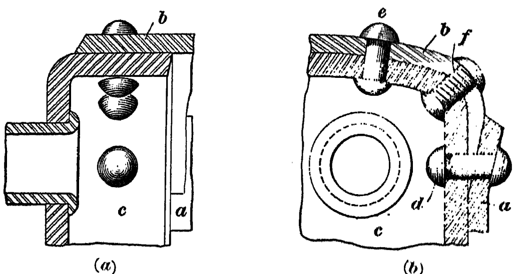


FIG. 30

nection between the side sheet *a*, the crown sheet *b*, and the tube-sheet *c*. If the tube-sheet is flanged to a very small radius in the corner, it is very difficult to drive a rivet properly midway between the rivets *d* and *e* in (*b*), that is, directly in the corner. The usual practice is to drill and tap a hole at this point, generally using a tap $\frac{3}{4}$ inch in diameter and having twelve threads per inch. A plug *f* is then screwed tightly into the tapped hole and its ends are riveted over and calked.

31. Fire-Cracks in Joints.—It has been found by experience that in firebox boilers the furnace side of the furnace sheets is liable to crack at the joints from the rivet holes outwards toward the edge of the plate, such cracks being termed *fire-cracks*. The lap joints are kept relatively cool on the

HEADS OF BOILERS AND DRUMS

FLAT HEADS

33. The tube-sheets of locomotive, vertical, flue, and horizontal return-tubular boilers are flat circular plates with flanges at the outer edges, by which they are riveted to the shells of the boilers. As a general rule, the tube-sheet, or head, is inserted in the manner shown in Fig. 21 (*b*); that is, the edge of the flange is inside the shell and the convex part

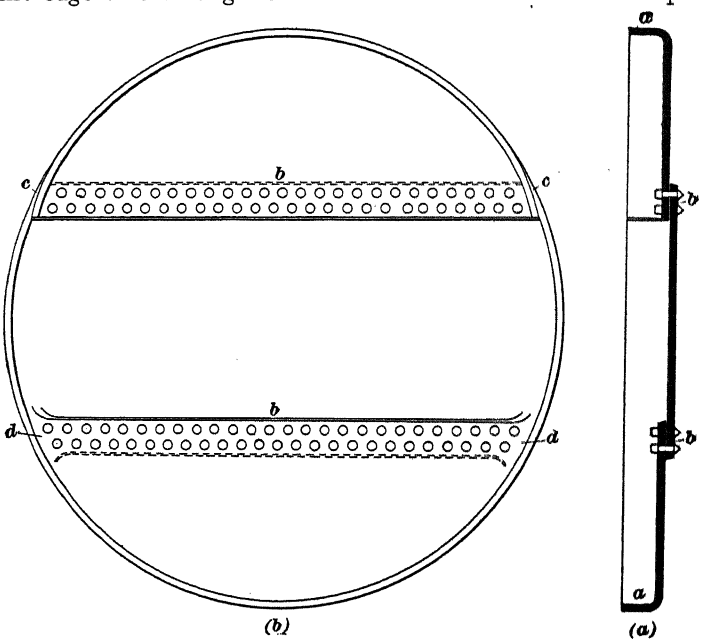


Fig. 33

of the flange faces outwards. However, it is not uncommon for the head to be backed in, as in (*c*), in which case the flat part of the head lies well within the outer end of the shell. As flat surfaces are not self-supporting when subjected to pressure, the flat heads of boilers are braced by diagonal stays above the tubes and by through stays, from head to head, below the tubes and on each side of the manhole

the furnaces to the head is turned in as shown at *b* in the sectional view. The tube holes *c* are drilled in the section *d* and the manholes *e* and handhole openings *f* are cut in the lower plate. The manhole openings may be flanged in, in the same manner as the furnace openings, or they may be reinforced by riveting wrought-iron or steel rings to the head, as shown at *g*.

BUMPED HEADS

35. Heads that are bent to the convex and concave forms shown in the sectional views, Fig. 35 (*a*) and (*b*), are called *bumped heads*, or *dished heads*. They are used in plain cylindrical boilers, steam drums, mud-drums, oil tanks, air reservoirs, etc. The head in (*a*) is convex outwards and is therefore a convex head, whereas the head in (*b*) is concave outwards and is a concave head. A dished head backed in, as shown in (*b*), is used only in cases where there is in the shell no opening large enough to permit the driving of the rivets.

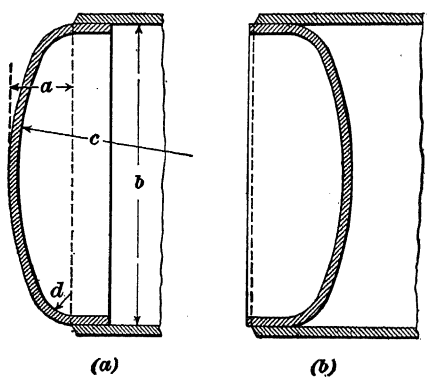


FIG. 35

Dished heads with the pressure on the convex side of the head, as in (*b*), are not so strong to resist pressure as heads having the pressure on the concave side, as in (*a*). The A. S. M. E. Boiler Code provides that a bumped head having the pressure against the convex face, as in (*b*), shall be allowed a maximum working pressure of only 60 per cent. of that for a bumped head of the same dimensions but having the pressure against the concave face, as in (*a*).

The depth *a* of the dished part of the head depends on the inside diameter *b* of the shell to which the head is riveted. The curve of the dished head has a radius *c* equal to the inside diameter *b* of the shell. The corner radius *d* is not less than

DOMES AND DRUMS

STEAM DOMES

37. Domes on Stationary Boilers.—In small fire-tube boilers of the locomotive, horizontal return-tubular, and flue types, domes of the form shown in Fig. 39 are very often attached at the top of the boiler shell. A dome is placed on a boiler for the purpose of increasing the steam space and also for the purpose of obtaining drier steam, the supposition being that the steam will be drier on account of its being farther removed from the water. The dome shell *a* in (*a*) is flanged and riveted to the boiler shell *b*. A flanged head *c* closes the dome at the top. To support the flat surface of the head, either of the methods of bracing shown in (*a*) and (*b*) may be employed. In (*a*) the stays *d* are threaded and screwed into the boiler plate *b*, the dome liner *e*, and the head *c*, and the ends are then headed over. The method of bracing shown in (*b*) consists of using diagonal braces *a* having at each end a palm or foot *b* parallel to the surface to which it is riveted.

38. Communication between the steam space and the dome may be provided by cutting a number of small holes *f*, Fig. 39 (*a*), through the shell plate below the dome; or, a single opening may be cut in the boiler shell, as in (*b*). In either case the total cross-sectional area of the opening or openings should be greater than the area of the steam outlet. The openings in the shell reduce its strength, and to compensate for its weakened condition the practice is to rivet a reinforcing ring, or liner, around the dome connection as at *e* in (*a*). The rivets *g* that hold the dome to the shell pass through both the liner and the shell. Drain holes *h* are also provided in the boiler shell near the lowest point of the junction of the base of the dome and the boiler shell. Water that collects from the condensation of steam flows back through these holes into the boiler.

An approximate rule for determining the size and height of a steam dome is to make its diameter equal to one-half the

diameter of the boiler, and its height equal to nine-sixteenths of the diameter of the boiler.

39. Locomotive Boiler Domes.—The domes of locomotive boilers are usually made of heavier plate than those of stationary boilers. The principal types of locomotive domes are shown in Figs. 40 and 41. The three-piece dome shown in Fig. 40, which is quite common, is made with a heavy collar or base *a*, from $\frac{3}{4}$ to 1 inch in thickness, having two flanges of about the same length. One of these flanges is riveted to the boiler shell and the other to the dome shell *b*. The shell *b* is made of lighter plate than the dome base and is closed at the top by a flanged flat head *c*. Domes are also formed in one piece, as illustrated in Fig. 41. This method of construction produces the strongest type of dome and offsets the need of several riveted joints. Such domes are pressed out of heavy plate, from $\frac{3}{4}$ to 1 inch thick. It will be noticed in (*a*) that the dome has a slight taper, being 29 inches in diameter at the top and 30 inches at the base. Owing to the heavy plate thickness the right-angle flanges are made with a large radius *a* of $4\frac{1}{2}$ inches, and a radius *b* of 3 inches is used for the larger flange angle, as shown in (*b*).

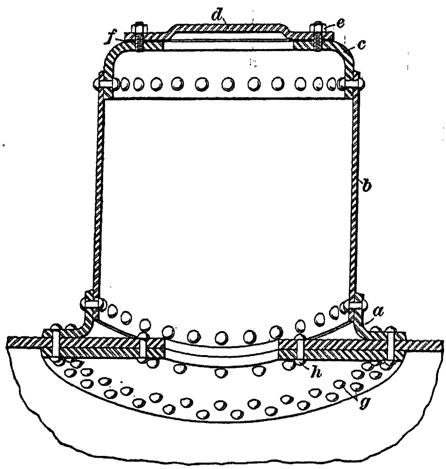


FIG. 40

40. In boilers of the locomotive type it is usually necessary to have a large opening in the dome head to permit the erection of the steam pipe and the throttle valve. Such an opening is circular in form and covered with a pressed-steel cap *d*, Fig. 40, which is fastened to the dome head by studs and nuts *e*. The upper surface of the dome head and the

of the lap-joint type, and the flange may be single-riveted to the boiler, provided that a factor of safety of not less than 8 is used in determining the allowable working pressure on the dome.

The corner radius of the flange, measured on the inside of the plate, shall equal at least twice the thickness of the plate, for plates 1 inch thick or less, and at least three times the plate thickness for plates over 1 inch in thickness.

The dome may be located on the barrel or over the firebox on traction, portable, and stationary boilers of the locomotive type, up to and including a shell diameter of 48 inches. For larger boiler diameters, the dome shall be located on the shell of the boiler.

42. Dry Pipe.—The use of steam domes is giving way to the practice of installing larger boilers with the required steam space and placing inside a fitting known as a *dry pipe*. It is usually made as shown in Fig. 42. The central section *a* is a tee into which are screwed the pipes *l* and *c* and the nipple *d*. The pipes *b* and *c* are slotted along the top, or else holes are drilled through them, as shown. The combined area of these openings should be larger than the cross-sectional area of the steam outlet *e*. It is usually one-third greater than the area of the steam outlet. The ends of the dry pipe are closed with caps *f* and at the bottom of the pipe a drip hole is drilled to allow water to drain out. The dry pipe should be connected at the highest point in the steam space of the boiler, and in such a manner that the steam can enter it through the perforations at the top. It is supported at the ends by iron straps *g* riveted to the drum *h*.

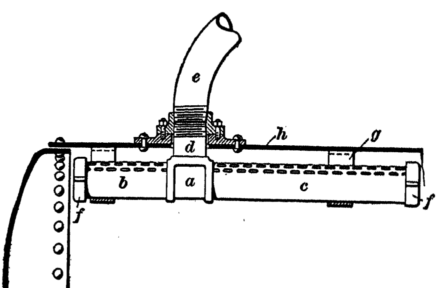


FIG. 42

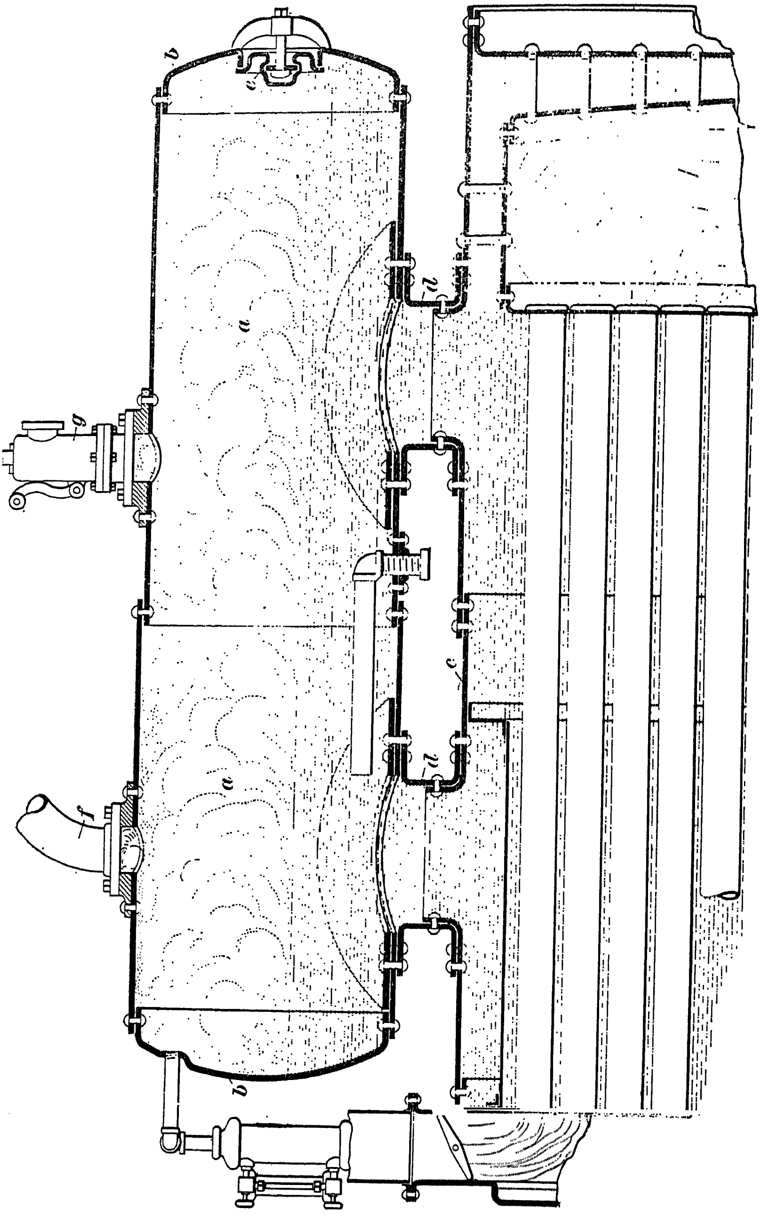


Fig 43

manhole *d* is provided in the end of the drum for cleaning and repairs, and blow-off piping *e* is connected at the bottom of the drum for blowing out the mud and other sediment. A protecting wall of brick may be built in front of the drum when it is placed inside the boiler setting, so that it may not be directly exposed to the fire temperature. The difficulty arising in the use of such drums is that the mud deposited tends to become baked and hard, and unless the drum is frequently cleaned, there is danger of its becoming entirely clogged. In some types of water-tube boilers one or more cylindrical drums form water-drums and mud-drums, serving primarily to distribute the feedwater to the tubes and incidentally to collect mud and other feedwater sediment.

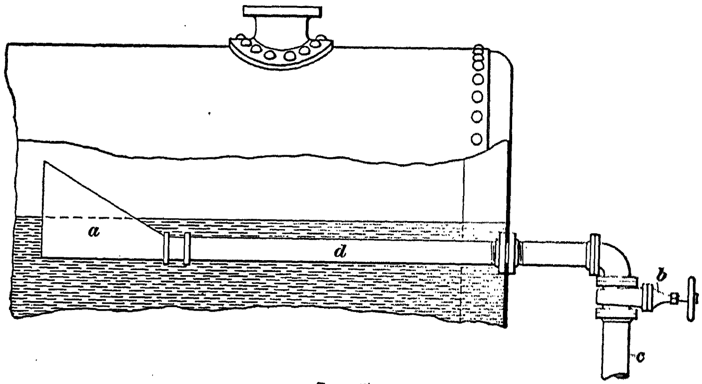


FIG. 45

47. Surface Blow-Off.—The surface blow-off *a*, Fig. 45, is a sheet-metal funnel or scoop so arranged that its outlet is submerged at the lowest water level and its upper edge at the highest water level. It should be placed at about one-third of the length of the boiler from the rear head. It is installed for the purpose of removing the scum and other impurities that rise to the surface of the water. When the valve *b* is opened, the steam pressure forces the scum and some water to flow out through the blow-off piping *c* which is usually connected to a blow-off tank. If the scum is not removed, it will prove detrimental to the operation of the boiler, for it will

OPENINGS IN BOILERS

STEAM, WATER, AND WASHOUT OPENINGS

49. Classes of Openings.—In all types of boilers, a number of holes, or openings, must be cut through the boiler shells, heads, domes, or drums for the outlet of steam, for the inlet and outlet of water, and for the purposes of cleaning, inspecting, and repairing. It is customary to designate each opening in accordance with the purpose it serves; thus, the hole through which the feedwater is admitted is the feedwater hole; the hole into which a gauge cock is screwed is the gauge-cock hole. An opening cut into a boiler for the purpose of washing out foreign matter and incidentally permitting inspection is an inspection hole, a washout hole, or a handhole, the last term being preferably used when the hole is large enough to admit the hand. When a hole is large enough to permit the passage of a man's body it is a manhole. One or more manholes should be placed in each boiler that is large enough to permit this, one manhole being placed in the front head and another in the boiler shell. Sometimes a manhole is placed in the rear head instead of in the boiler shell.

50. Washout Holes and Plugs.—In locomotive-type boilers, washout holes are placed in convenient places in the water legs below and above the tubes, for washing out mud and other sediment that collects in the boiler. These openings are threaded and plugged. Round brass plugs for closing washout holes are called *washout plugs*. They generally have twelve threads per inch, cut on a taper of $\frac{3}{4}$ inch per foot. Two types of washout plugs are used, differing only in the manner of receiving the wrench for screwing them in or out. The form shown in Fig. 47 (*a*) is a male plug, and is the one most generally used; the form shown in (*b*) is a female plug, and is used only where the projecting square shank of the male plug is not permissible. The body of the female plug is recessed to receive the wrench by which it is screwed into place.

resisting and waterproof material when used for steam connections. Various compositions of rubber and asbestos are employed for this purpose. Before being placed in position the gasket should be coated on both sides with graphite in

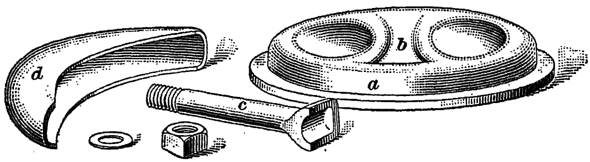


FIG. 49

order to prevent it from sticking to the metal when the cover is removed. It may then be used a number of times. The different parts of an elliptical pressed-steel handhole cover-plate are shown in Fig. 49. The plate *a* is formed under hydraulic pressure and the two curved transverse ribs provide

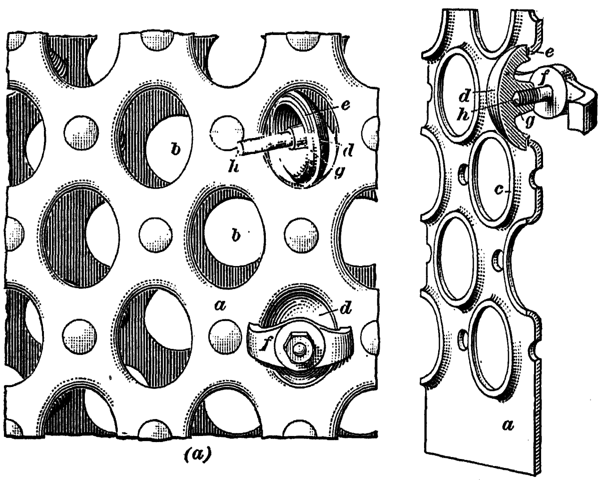


FIG. 50

a socket *b* into which is slipped the head of the bolt *c*. The yoke *d* is also of pressed steel, and the combination of plate and yoke gives a stronger and lighter form of handhole cover arrangement than the cast-iron or steel type.

of the plug is circular, it cannot be put in from the outside through the circular opening that it closes. Instead, *master handholes,* as shown in Fig. 52, are provided in the bottom of the headers, through which the tapered plug is inserted and

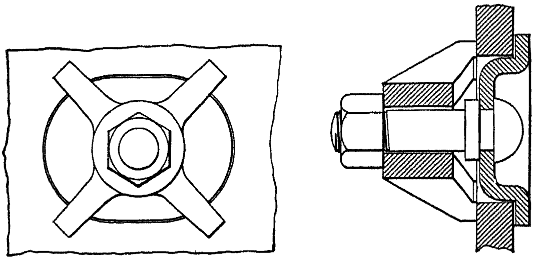


FIG. 52

then placed in the circular opening. When a handhole opening exceeds 6 inches in any dimension, the metal around the opening must be reinforced by a steel ring or liner.

MANHOLES

55. In general, the construction of a manhole and its cover does not differ materially from that of a handhole and its cover, except that the former is larger, being 10 in. by 14 in., 11 in. by 15 in., or 12 in. by 16 in. The usual size is 11 inches by 15 inches. A manhole should be cut in a boiler shell with the long diameter, or long axis, parallel to the girth seam,

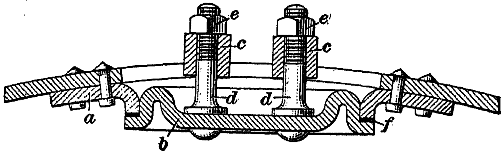


FIG. 53

because the stress per inch of girth seam is only half as great as the stress per inch of longitudinal seam. As the shell is materially weakened by cutting such a large hole, it is necessary to reinforce the plate around the manhole opening. The general practice in reinforcing manholes in shell boilers is to

WATER AND STEAM-PIPE OPENINGS

57. Reinforcement of Pipe Openings.—If water pipes or steam pipes that enter the head, shell, dome, etc., of a boiler are rather small and the plate is relatively thick, they may be screwed directly into the plate; but if such pipes are comparatively large, the plate must be reinforced where the pipes enter. The manner in which plates are reinforced at pipe openings depends somewhat on the size of the pipe and the thickness of the plate, and, in case a boiler fitting is attached, on the character of the fitting. The respective boiler rules specify how the pipe openings and other fitting connections should be reinforced. The A. S. M. E. Boiler Code contains the following requirements as to pipe connections to boilers: "If the thickness of the material in the boiler is not sufficient to give the required number of threads in accordance with Table I, the opening shall be reinforced by a pressed-steel, cast-steel, or bronze-composition flange, or plate, so as to provide the thickness of plate for the required number of threads."

TABLE I

MINIMUM NUMBER OF PIPE THREADS FOR BOILER CONNECTIONS

Size of Pipe Connection Inches	Number of Threads per Inch	Minimum Number of Threads Required in Opening	Minimum Thickness of Material Required Inches
1 and $1\frac{1}{4}$	$11\frac{1}{2}$	4	.348
$1\frac{1}{2}$ and 2	$11\frac{1}{2}$	5	.435
$2\frac{1}{2}$ to 4	8	7	.875
$4\frac{1}{2}$ to 6	8	8	1.000
7 and 8	8	10	1.250
9 and 10	8	12	1.500
12	8	13	1.625

58. Reinforcing Small Pipe Openings.—Small openings that are to be tapped for pipes not exceeding $1\frac{1}{2}$ inches nominal diameter usually have the holes reinforced with a triangular liner *a*, Fig. 56, which is riveted to the inside of the shell plate

opening in the plate *c*. The internal thread *d* permits turning the feed-pipes *e* and *f* into position. In tubular boilers, bushings of this kind are used extensively, being secured to the front head of the boiler and calked to prevent any possibility of leakage.

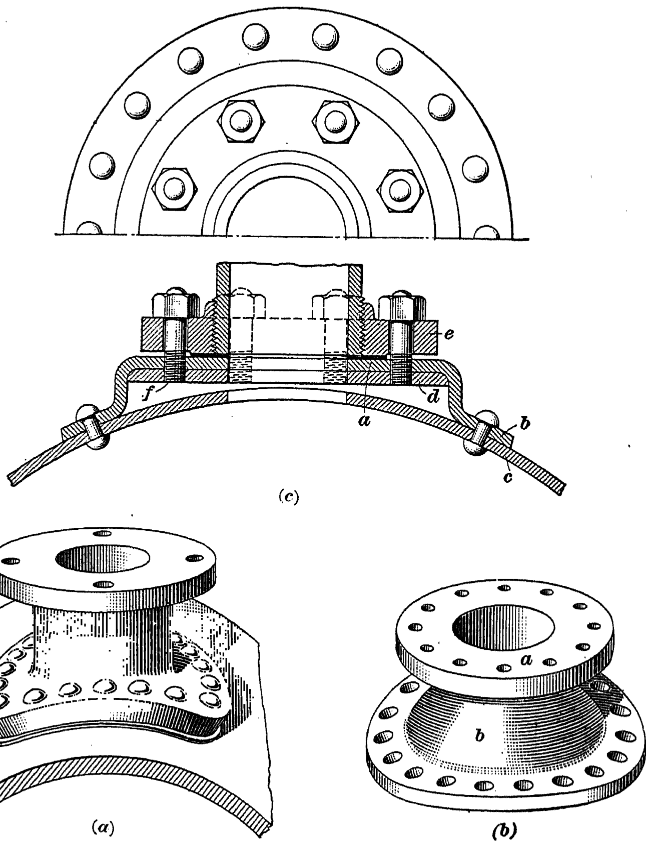


FIG. 60

59. Boiler Nozzles.—For openings $2\frac{1}{2}$ inches in diameter and larger it is necessary to use flanged fittings called *nozzles*. Such fittings are made of steel or iron castings of the form shown in Fig. 60 (*a*), or of pressed steel of the form shown in (*b*). The latter construction is the stronger and is best

case the stay braces a flat surface, it will make an angle of 90 degrees with that surface; and if it is applied to a curved surface, it will be normal to it at the point of application. By *normal* is meant that the stay is at right angles to a straight line tangent to the surface at the point of application. A diagonal stay is a stay that is not placed at right angles to the surface it supports. A girder stay is a stay in the form of a girder, and is subjected to bending stresses produced by the load.

TYPES OF DIRECT STAYS

3. Solid Screw Staybolt.—A common form of solid screw staybolt, which is used for bracing in the small water spaces of locomotive-type and vertical boilers, is shown in Fig. 1. The staybolt, which is threaded for its entire length, is screwed into place, after which the ends are riveted over. The thread employed for screw stays is the United States standard, or 12 threads per inch.

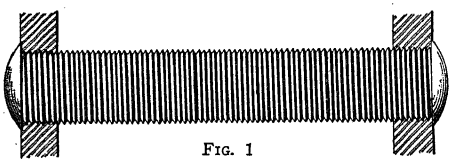


FIG. 1

4. Screw Staybolt With Telltale Hole. An improved form of screw staybolt used extensively for staying flat plates and internal fireboxes of vertical fire-tube boilers is shown in Fig. 2 (*a*). Only the ends are threaded, leaving the body of the stay smooth, as a smooth surface is not attacked so readily as a threaded surface by the corrosive elements of the feedwater. A hole *a*, called a *telltale hole,* is drilled into one or both ends of the staybolt, this hole having a diameter of from $\frac{3}{16}$ inch to $\frac{1}{4}$ inch and a depth of from 1 inch to $1\frac{1}{4}$ inches. When such a staybolt breaks, which, in locomotive-type boilers, occurs near the outside sheet, water or steam escaping through the crack and the hole *a*, as shown in (*b*), gives warning of the break. Many engineers prefer to have the telltale hole extended through the entire length of the staybolt, as shown in Fig. 3. A staybolt with a hole extending from end to end is called a *hollow staybolt.*

on without any mixture or preparation; but in marine work, it is the usual practice to calk the sheets around the body of the bolt before applying the nuts.

6. Through Stays.—A long stay passing through the boiler from head to head is called a *through stay*, a *stayrod*, or

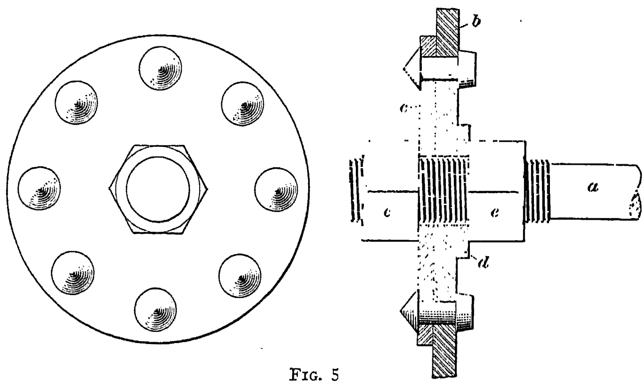


FIG. 5

an *end-to-end stay*. A common construction of one end of a stayrod is shown in Fig. 5. The end of the stayrod *a* is enlarged and threaded, and passes through a hole in the plate *b*, the hole being slightly larger than the threaded end of the stay-

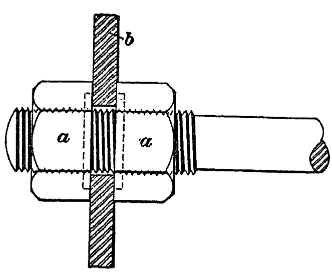


FIG. 6

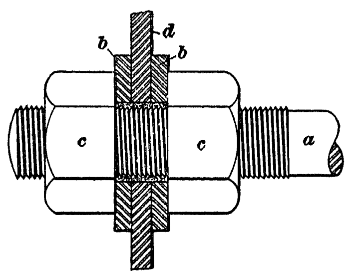


FIG. 7

rod. A large washer *c* is placed on the outside of the plate *b* and riveted to it, thus strengthening the head. A small washer *d* is usually placed on the inside. Nuts *e* lock the stayrod to the plate. Instead of using a large washer for each stayrod, a *stiffening plate*, often called a *doubling plate*, is used. This plate

only to tension but also to bending as the result of repeated expansion and contraction of the boiler plate. To overcome the breakage caused by this bending, flexible staybolts have been designed. There are two principal forms of the screw type, as shown in Fig. 10 (*a*) and (*b*). The standard screw type shown in (*a*) is used extensively in the water legs of locomotive boilers. The inner end *a* of the staybolt is threaded and screwed into the firebox sheet *b*. The head *c* of the outer end is partly

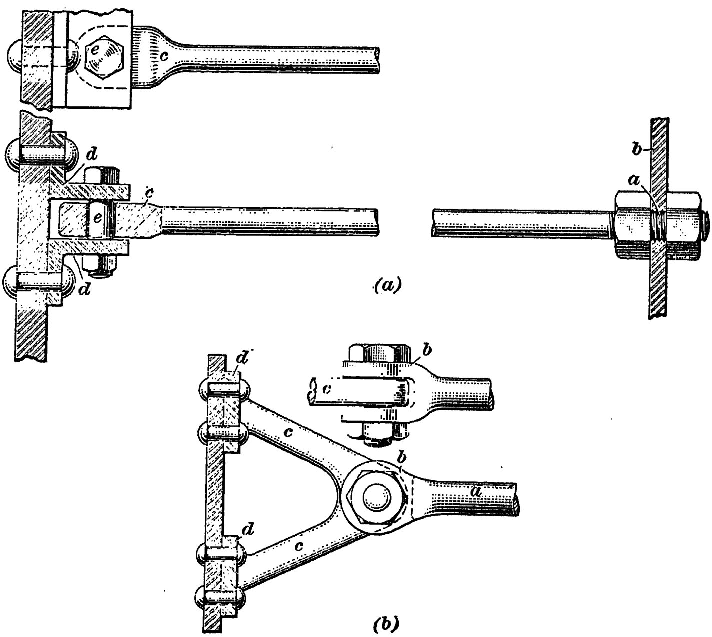


FIG. 9

spherical and fits a spherical seat in the sleeve *d*, which is screwed into the outside sheet *e*. The sleeve *d* is enlarged on the inside at *f* to permit the stay *a* to move freely in accommodating itself to the movement of the firebox sheets. A cap nut *g* is screwed over the sleeve to make a steam-tight joint. After the stay has been screwed in place, the threaded end is headed, as shown, and during the riveting process a bar with a spherical recess is held against the opposite end.

tubes when threaded must not be less than $\frac{3}{16}$ inch thick, measured at the bottom of the thread. The body of the tube is made about $\frac{1}{4}$ inch smaller than at the threaded end, so that after the threaded end has been screwed through the first sheet, the tube can be easily shifted to install it in the second sheet, and then both ends can be screwed into the tube-sheets at the same time. In the construction shown in (*b*), a nut is screwed over the end of the tube, to bear against the tube-sheet. Nuts on stay-tubes are not advised where such tubes are used in staying the heads of tubular boilers, because the heat will burn the nuts away.

DIAGONAL STAYS

12. Radial Stays.—In locomotive boilers, the shape of the firebox and the outside furnace sheet is often such that it is

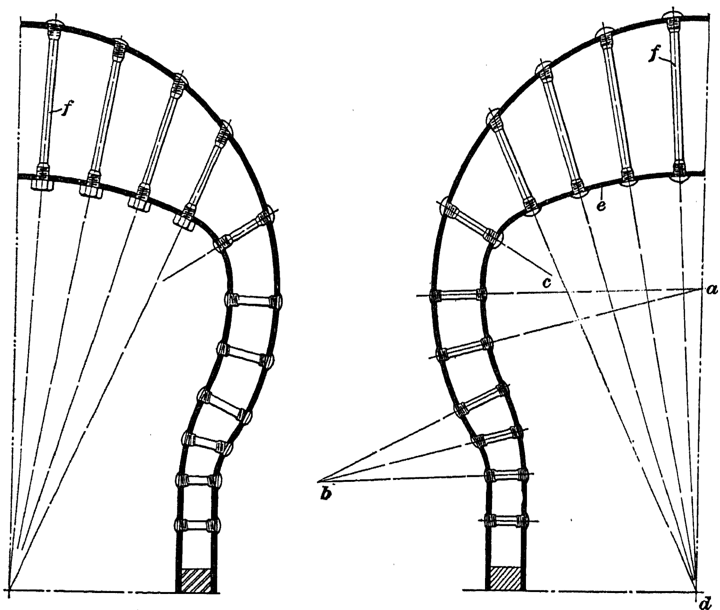


FIG. 12

convenient to brace the entire firebox with screw stays, arranged as shown in Fig. 12 (*a*). It will be noticed that various groups

14. The firebox ends of some crown stays are formed as shown in Fig. 14. The stay shown in (*a*) is an ordinary screw

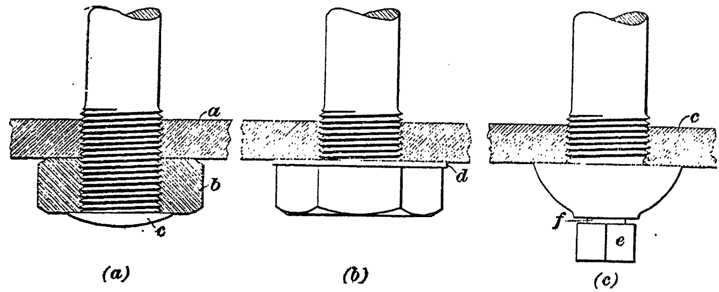


Fig. 14

stay screwed into the crown sheet *a*. When set in place the nut *b* is screwed tight against the crown sheet, and the end of

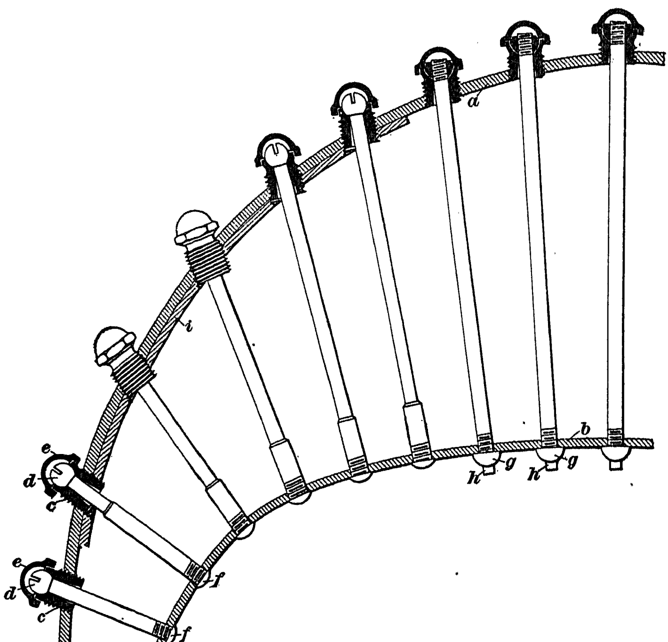


Fig. 15

the bolt is then riveted over as at *c* to retain the nut *b* in place. The crown bolt shown in (*b*) has a solid hexagonal head

This form of stay is used in bracing boiler heads of internally fired boilers, but the rigidity of the stay is objectionable as it

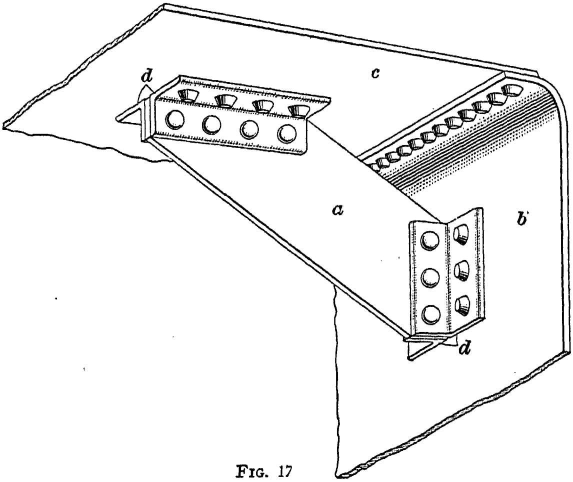


FIG. 17

localizes the stresses on the connecting boiler plates. With the construction shown, the rivets in the ends of the gusset are in double shear; but if a tee iron is used instead of the pair of angles, the rivets at the connection with the gusset will be in single shear. When tees or angles are used to connect diagonal braces to heads, they should be placed as shown in Fig. 18, in lines radiating from the center of the head.

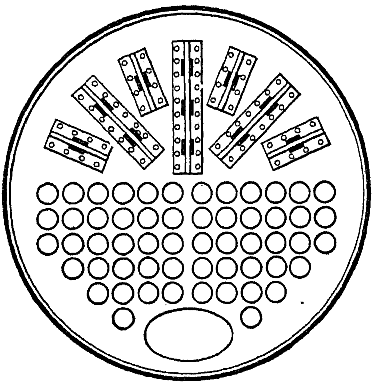


FIG. 18

17. Diagonal Stays. That part of a tube-sheet that does not receive support from tubes—as, for example, the segment of a flat head above the upper row of tubes in a tubular boiler—must be stayed. A common form of stay used for this purpose is the diagonal stay. It may consist of a rod welded at the ends to flat pads that are riveted to the head and

made in one operation by heating a piece of sheet steel, splitting one end to form the crowfoot, and bending the other to the desired angle, all under heavy pressure. Because of the manner in which the branches at the end are split and bent outwards, this type of brace is frequently termed a *crowfoot brace*. Another form of diagonal stay, known as the Huston crowfoot brace, is shown in (*b*). The body of the brace is doubled, thus enabling the foot to be made solid, without splitting. The palm end is formed to a channel shape, producing a strong brace.

GIRDER STAYS

19. Girder Stays in Scotch Boilers.—The tops of the combustion chambers of Scotch boilers are usually supported by girder stays, also called *crown bars*. In Fig. 21 is shown how

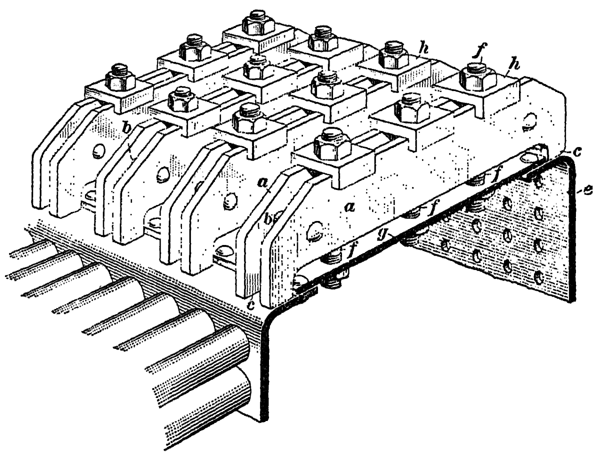


FIG. 21

girder stays are arranged over the top of a combustion chamber. Each girder consists of two steel plates *a* of the same shape and thickness, set side by side and held at a fixed distance from each other by thimbles *b* through which pass rivets that hold the plates *a* together. This built-up girder is placed on top of the combustion chamber, with its ends *c* resting on the upper

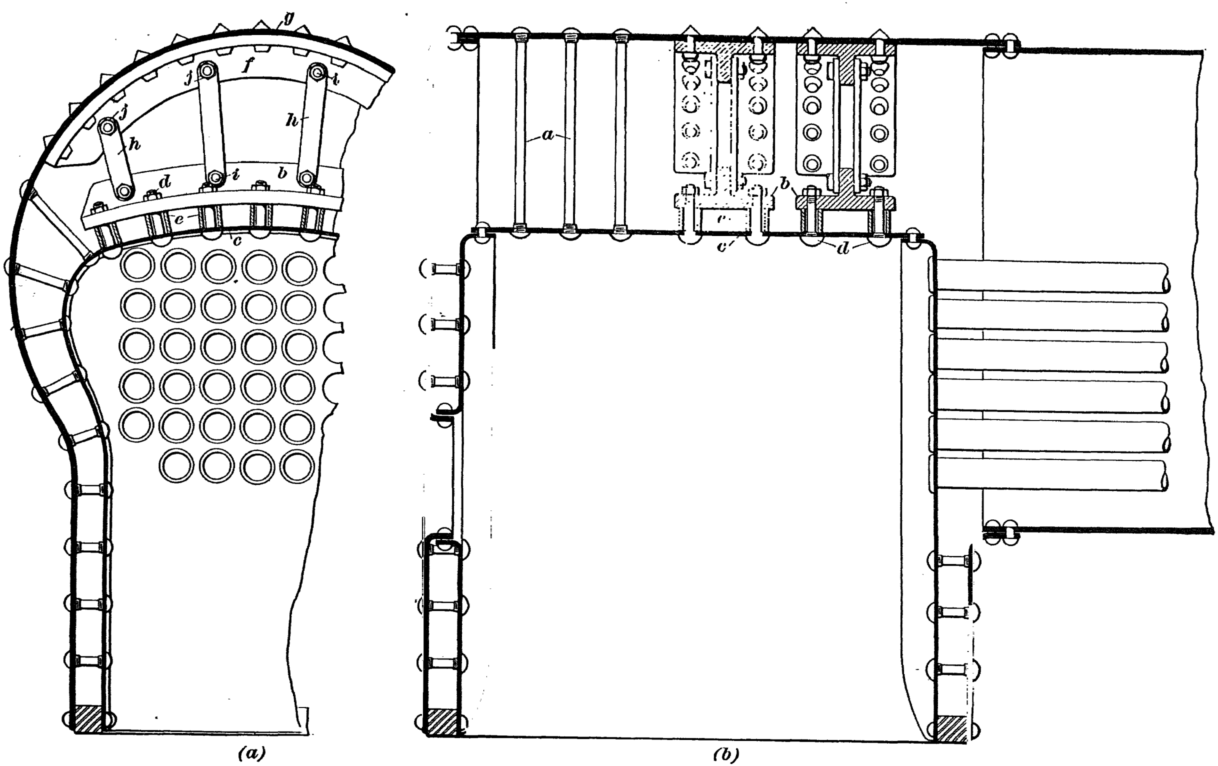


FIG. 23

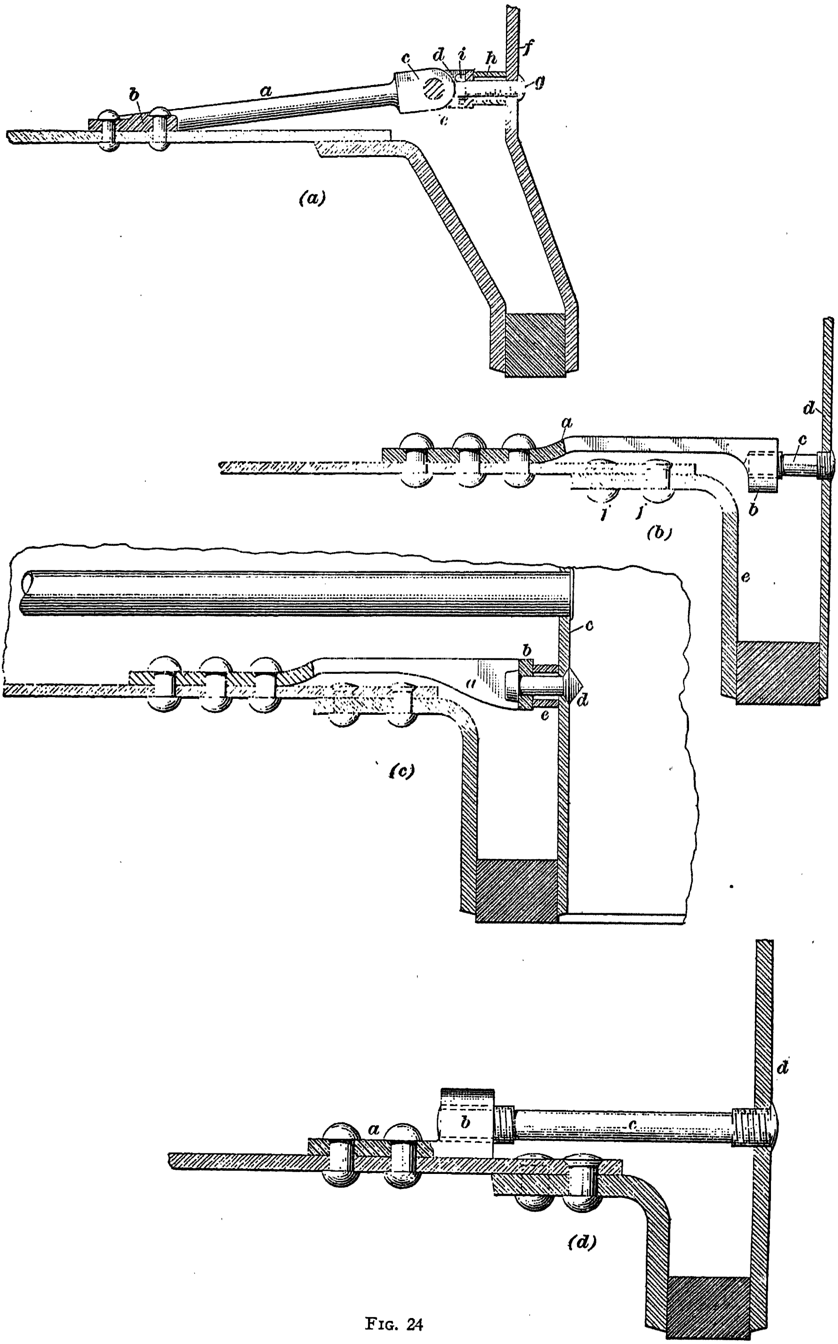


Fig. 24

24. Steel Angle Stays.—For the upper segments of tube heads of boiler shells not exceeding 36 inches in diameter, and when the boilers are designed to carry a working pressure not greater than 100 pounds per square inch, the method of bracing shown in Fig. 25 may be employed. The steel angles are placed back to back so that their short legs *a* can be riveted to

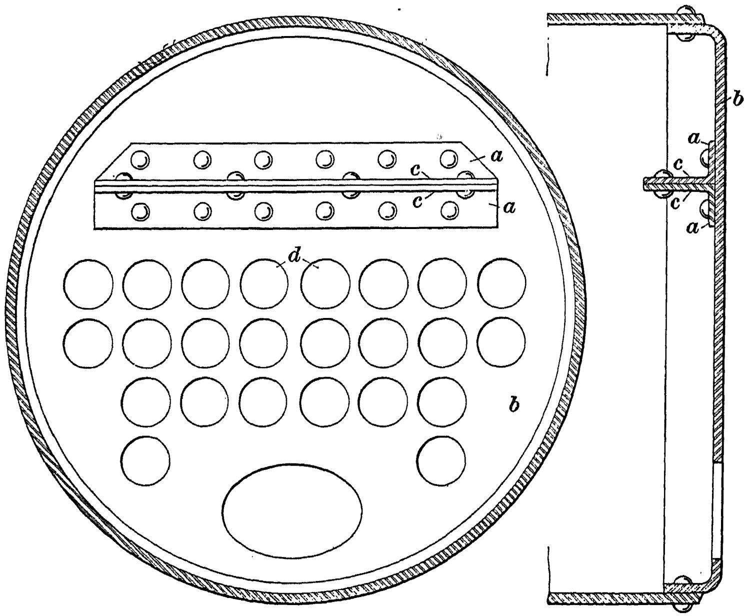


FIG. 25

the boiler head *b*. The projecting legs *c* of the angles are also riveted together. The spacing of the rivets in the legs *c* should not be over 8 inches and the spacing of the rivets attaching the angles to the boiler head should not be over 4 inches. The bottom of the lower angle should be not less than 2 inches above the top row of tubes *d*. Rivets of the same diameter as are used in the boiler shell should be used for this method of bracing.

locomotives. Seamless steel tubing is produced from a round steel billet that is placed in a furnace and heated to a white heat. The billet is then pushed by special machinery and at the same time pierced by a pointed mandrel, which produces a rough tube several times as long as the original billet. The next process consists in rolling the rough tube over a mandrel, whereby the thickness of the tube wall and the diameter are

TABLE I

DIMENSIONS AND WEIGHTS OF BOILER TUBES

Outside Diameter Inches	Thickness of Wall		Theoretical Weight per Foot	Length of Tube in Feet per Square Foot of	
	Inch	B. W. G.	Pounds	External Surface	Internal Surface
1	.095	13	.918	3.820	4.715
1¼	.095	13	1.171	3.056	3.604
1½	.095	13	1.425	2.546	2.916
1¾	.095	13	1.679	2.182	2.448
2	.095	13	1.932	1.909	2.110
2¼	.095	13	2.186	1.697	1.854
2½	.109	12	2.783	1.527	1.673
2¾	.109	12	3.074	1.388	1.508
3	.109	12	3.365	1.273	1.373
3¼	.120	11	4.011	1.175	1.269
3½	.120	11	4.331	1.091	1.171
3¾	.120	11	4.652	1.018	1.088
4	.134	10	5.532	.954	1.023
4½	.134	10	6.248	.848	.902
5	.148	9	7.669	.763	.812

reduced and the rough tube is converted into a longer and smoother tube. The tubing is then passed through a burnishing machine to give it a smooth burnished surface, after which it is sized through finishing rolls that produce the required outside diameter. Tubes manufactured in this manner are known as *hot-rolled seamless tubes*. *Cold-drawn seamless tubes* are

TABLE II

DIMENSIONS OF BOILER TUBES WITH UPSET ENDS

Outside Diameter of Tube Inches	Thickness of Tube													
	B. W. G.							Inch						
	10	9	8	7	6	5	4	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{5}{16}$	$\frac{11}{32}$	$\frac{3}{8}$	$\frac{13}{32}$	$\frac{7}{16}$
	Outside Diameter of Upset End, in Inches													
$1\frac{1}{2}$	1.63	1.65	1.67	1.69	1.70	1.72	1.74	1.75	1.78	1.81	1.84	1.88	1.91	1.94
$1\frac{3}{4}$	1.88	1.90	1.92	1.94	1.95	1.97	1.98	2.00	2.03	2.06	2.09	2.13	2.16	2.19
2	2.13	2.15	2.17	2.19	2.20	2.22	2.24	2.25	2.28	2.31	2.34	2.38	2.41	2.43
$2\frac{1}{4}$	2.38	2.40	2.42	2.44	2.45	2.47	2.49	2.50	2.53	2.56	2.59	2.63	2.66	2.69
$2\frac{1}{2}$	2.63	2.65	2.67	2.69	2.70	2.72	2.74	2.75	2.78	2.81	2.84	2.88	2.91	2.94
$2\frac{3}{4}$	2.88	2.90	2.92	2.94	2.95	2.97	2.98	3.00	3.03	3.06	3.09	3.13	3.16	3.19
3	3.13	3.15	3.17	3.19	3.20	3.22	3.24	3.25	3.28	3.31	3.34	3.38	3.41	3.44
$3\frac{1}{4}$	3.38	3.40	3.42	3.44	3.45	3.47	3.49	3.50	3.53	3.56	3.59	3.63	3.66	3.69
$3\frac{1}{2}$	3.63	3.65	3.67	3.69	3.70	3.72	3.74	3.75	3.78	3.81	3.84	3.88	3.91	3.94
$3\frac{3}{4}$	3.88	3.90	3.92	3.94	3.95	3.97	3.98	4.00	4.03	4.06	4.09	4.13	4.16	4.19
4	4.13	4.15	4.17	4.19	4.20	4.22	4.24	4.25	4.28	4.31	4.34	4.38	4.41	4.44
$4\frac{1}{4}$	4.38	4.40	4.42	4.44	4.45	4.47	4.49	4.50	4.53	4.56	4.59	4.63	4.66	....
$4\frac{1}{2}$	4.63	4.65	4.67	4.69	4.70	4.72	4.74	4.75	4.78	4.81	4.84	4.88	....	....
$4\frac{3}{4}$	4.88	4.90	4.92	4.94	4.95	4.97	4.98	5.00	5.03	5.06	5.09	....	....	....
5	5.13	5.15	5.17	5.19	5.20	5.22	5.24	5.25	5.28	5.31	....	....	....	....

at the end *d,* which may be done by using the ball end of the boilermaker's hammer, or with a flaring tool, which is tapering in form and operated by an air hammer. After the ends are flared, they are beaded, as shown at *e*, by the use of a beading tool, or *boot tool,* which is made as shown in Fig. 28 (*a*) for hand beading. For beading done by the use of an air hammer, a tool of the same shape is used, having at the end a circular shank, as shown in (*b*), which is inserted in the driving end of the air hammer. The beading tool should be held in about the position indicated so that the bead is brought down over the edge of the plate; otherwise, the bead may be forced away from the tube-sheet, resulting in leaky tubes.

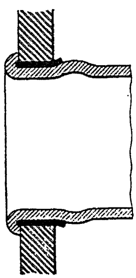


FIG. 29

31. In the installation of tubes in Scotch boilers, the tube *a,* Fig. 27, is inserted from the front head of the boiler. The ends of the tubes in the combustion chamber are set to project $\frac{1}{4}$ inch beyond the combustion-chamber tube-sheet, and at the front end from $\frac{1}{4}$ to $\frac{3}{8}$ inch outside the front head. Both ends are expanded and those in the combustion-chamber end are flared and beaded; but at the front end the tubes are usually expanded and flared. Stay-tubes having upset and threaded ends are extensively used in staying the heads of Scotch boilers.

Locomotive boiler tubes are installed in a similar manner except that a copper liner, or *ferrule,* is usually placed between the tube-sheet in the firebox and the tubes. Such liners take up the inequalities in the metal of the tube and plate, thus insuring a tighter connection. The ferrules are usually about $\frac{1}{16}$ inch thick and are set to extend about $\frac{1}{16}$ inch inside the hole from the tube-sheet, as shown in Fig. 29. It is also the practice to weld the bead of the tubes to the firebox tube-sheet to insure steam-tightness. Water tubes in water-tube boilers are expanded and flared.

FURNACE FLUES AND COMBUSTION CHAMBERS

CYLINDRICAL FURNACE FLUES

33. Plain Furnace Flue.—The simplest form of furnace flue is a plain cylinder of wrought-iron or steel plate, which may have a riveted longitudinal seam or may be welded. If conditions were such as to call for a comparatively large furnace flue and a high pressure, a plain furnace flue would have to be so thick as to interfere seriously with the transfer of heat from the fire to the water. To overcome this defect, plain furnace flues are stiffened by means of strengthening rings, which are attached to the outside, where they are in contact with the water in the boiler.

34. Furnace Flues With Strengthening Rings.—To strengthen the plain type of furnace flue, stiffening rings of

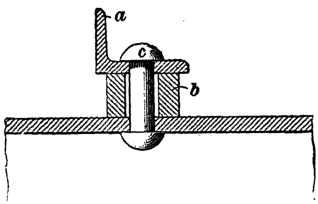


FIG. 30

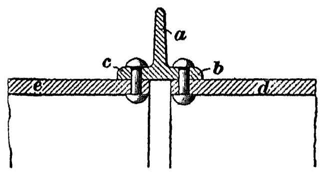
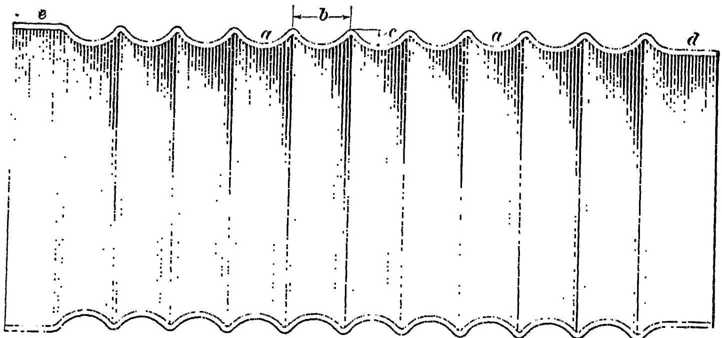


FIG. 31

angle iron or tee iron are attached to the outside. A common construction is shown in Fig. 30. The strengthening ring *a* is made of angle iron and encircles the flue, from which it is separated by a spool *b* placed around each rivet *c*. The spools hold the ring away from the flue and thus provide for a free circulation of water between them. The circulation of water next to the flue protects it from injury by the fire. A short furnace flue of a given diameter and thickness is much stronger than a long one of the same diameter and thickness; therefore, furnace flues are often made in sections united in such a manner as to secure great strength with comparatively thin material. Flues thus constructed are called *built-up furnace flues,* and also *sectional furnace flues.*

permit the furnace to expand and contract longitudinally, or in the direction of its length. Furnaces of this kind are made



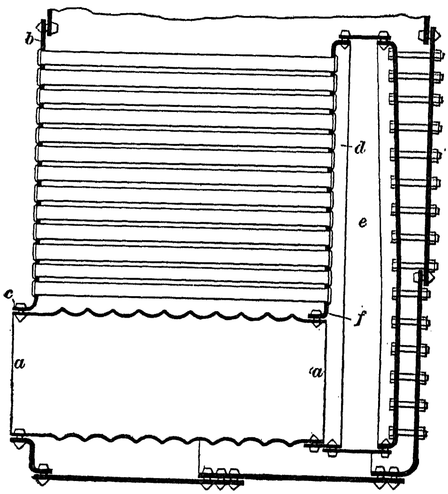


FIG. 34

from 28 to 60 inches in diameter, inside, and with a plate thickness of from $\frac{5}{16}$ to $\frac{3}{4}$ inch.

37. Morison Corrugated Furnaces.—In Fig. 34 (*a*) is illustrated the Morison suspension furnace. The curved sections *a*, called the corrugations, have a pitch *b* of 8 inches from center to center, the depth *c* of the corrugations being $1\frac{1}{2}$ inches.

The one shown in (*a*) has one plain inside end *a*, and the opposite end is cut away and flanged at *b*. The flanged portion extends only a short distance around the top of the furnace. The bottom section *c* is of the same shape as the end *a*. The other form, shown in (*b*), is known as the horse-collar type, on account of the shape of the oval end *a*, which in profile has the shape of a horse collar. The flange *b* is set flush against the side of the combustion-chamber head and riveted to it. The opposite end *c* is made of a plain circular form.

In replacing a furnace of the horse-collar type it is inserted into the front end of the boiler and raised off center, so as to give it a slant, thus allowing the upper flange *a* to slide inside the circular flange of the front head. After the furnace has been raised sufficiently so that the lower edge clears the bottom

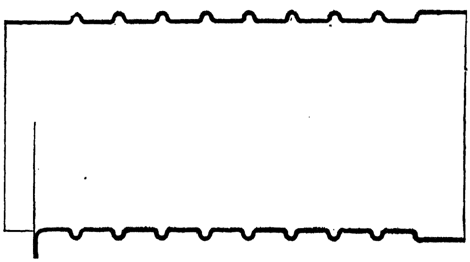


FIG. 36

flange of the head, it is swung so as to bring it central with the furnace opening. From this position it can be slid back against the tube-sheet of the combustion chamber.

39. Purves Ribbed Furnace.—A Purves ribbed furnace flue is shown in Fig. 36. The height of the ribs is $1\frac{3}{8}$ inches and the distance from center to center of ribs is 9 inches. The thickness of the flue must not be less than $\frac{7}{16}$ inch, and the length of the plain part of the ends not more than 9 inches. This form of flue is a modification of the built-up bowling-ring principle of construction.

There are other corrugated furnaces having similar construction, such as the following: the *Leeds corrugated furnace*, which has the corrugations pitched 8 inches between centers and not less than $2\frac{1}{4}$ inches deep; the *Fox corrugated furnace*, hav-

be, adjacent to the furnace, a combustion chamber in which the gases can burn.

42. Forms of Combustion Chambers.—Internally fired boilers have built-in combustion chambers. The combustion chamber is constructed of steel plates which are riveted and

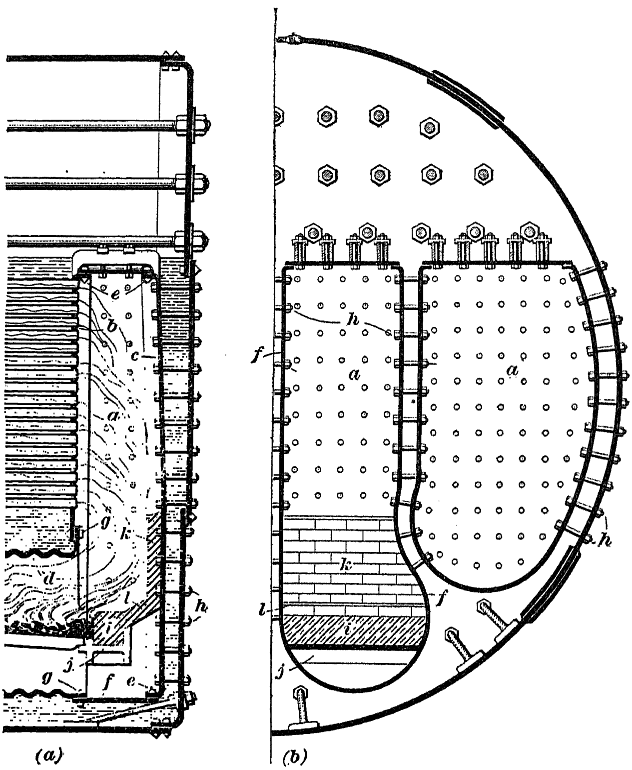


FIG. 37

stayed to withstand safely the steam pressure carried by the boiler. The design of the internal combustion chamber depends on the form of the boiler. Usually it is made circular at the bottom to conform to the curvature of the boiler shell. The upper plates are either straight or arched and are braced by suitable forms of stays.

Combustion chambers are sometimes constructed with round or arched backs, as shown at *a*, Fig. 38. The purpose of this is to facilitate the flow of the gases of combustion into the tubes, the curved top of the combustion chamber acting as a deflector for the gases. A sheet of this form does not require such extensive bracing as does a flat crown sheet.

TABLE I

DIMENSIONS OF STANDARD WROUGHT PIPE

Diameter			Thickness Inch	Circumference		Transverse Areas			Length of Pipe per Square Foot of		Length of Pipe Containing One Cubic Foot Feet	Nominal Weight per Foot Pounds	Number of Threads per Inch
Nominal Internal Inches	Actual External Inches	Approximate Internal Inches		External Inches	Internal Inches	External Square Inches	Internal Square Inches	Metal Square Inches	External Surface Feet	Internal Surface Feet			
1/8	.405	.270	.068	1.272	.848	.129	.0573	.0717	9.440	14.150	2,513.000	.241	27
1/4	.540	.364	.088	1.696	1.144	.229	.1041	.1249	7.075	10.490	1,383.300	.420	18
3/8	.675	.494	.091	2.121	1.552	.358	.1917	.1663	5.657	7.730	751.200	.559	18
1/2	.840	.623	.109	2.639	1.957	.554	.3048	.2492	4.547	6.130	472.400	.837	14
3/4	1.050	.824	.113	3.299	2.589	.866	.5333	.3327	3.637	4.635	270.000	1.115	14
1	1.315	1.048	.134	4.131	3.292	1.358	.8626	.4954	2.904	3.645	166.900	1.668	11½
1¼	1.660	1.380	.140	5.215	4.335	2.164	1.4960	.6680	2.301	2.768	96.250	2.244	11½
1½	1.900	1.611	.145	5.969	5.061	2.835	2.0380	.7970	2.010	2.371	70.660	2.678	11½
2	2.375	2.067	.154	7.461	6.494	4.430	3.3560	1.0740	1.608	1.848	42.910	3.609	11½
2½	2.875	2.468	.204	9.032	7.753	6.492	4.7840	1.7080	1.328	1.547	30.100	5.739	8
3	3.500	3.067	.217	10.996	9.636	9.621	7.3880	2.2430	1.091	1.245	19.500	7.536	8
3½	4.000	3.548	.226	12.566	11.146	12.566	9.8870	2.6790	.955	1.077	14.570	9.001	8
4	4.500	4.026	.237	14.137	12.648	15.904	12.7300	3.1740	.849	.949	11.310	10.665	8
4½	5.000	4.508	.246	15.708	14.162	19.635	15.9610	3.6740	.764	.848	9.020	12.490	8
5	5.563	5.045	.259	17.477	15.849	24.306	19.9900	4.3160	.687	.757	7.200	14.502	8
6	6.625	6.065	.280	20.813	19.054	34.472	28.8880	5.5840	.577	.630	4.980	18.762	8
7	7.625	7.023	.301	23.955	22.063	45.664	38.7380	6.9260	.501	.544	3.720	23.271	8
8	8.625	7.982	.322	27.096	25.076	58.426	50.0400	8.3860	.443	.478	2.880	28.177	8
9	9.625	8.937	.344	30.238	28.076	72.760	62.7300	10.0300	.397	.427	2.290	33.701	8
10	10.750	10.019	.366	33.772	31.477	90.763	78.8390	11.9240	.355	.382	1.820	40.065	8
11	11.750	11.000	.375	36.914	34.558	108.434	95.0330	13.4010	.325	.347	1.510	45.028	8
12	12.750	12.000	.375	40.055	37.700	127.677	113.0980	14.5790	.299	.319	1.270	48.985	8
13	14.000	13.250	.375	43.982	41.626	153.938	137.8870	16.0510	.273	.288	1.040	53.921	8
14	15.000	14.250	.375	47.124	44.768	176.715	159.4850	17.2300	.255	.268	.903	57.893	8
15	16.000	15.250	.375	50.260	48.480	210.060	187.0400	14.0200	.239	.248	.770	62.000	8

TABLE II

DIMENSIONS AND WEIGHT OF EXTRA-HEAVY WROUGHT PIPE

(*Crane Co.*)

Diameter			Nominal Thickness Inch	Circumference		Transverse Areas			Length of Pipe per Square Foot of		Length of Pipe Containing One Cubic Foot Feet	Nominal Weight per Foot Plain Ends Pounds
Nonimal Internal Inches	Actual External Inches	Approximate Internal Inches		External Inches	Internal Inches	External Square Inches	Internal Square Inches	Metal Square Inches	External Surface Feet	Internal Surface Feet		
$\frac{1}{8}$	.405	.215	.095	1.272	.675	.129	.036	.093	9.431	17.766	3,966.392	.314
$\frac{1}{4}$	.540	.302	.119	1.696	.949	.229	.072	.157	7.073	12.648	2,010.290	.535
$\frac{3}{8}$	.675	.423	.126	2.121	1.329	.358	.141	.217	5.658	9.030	1,024.689	.738
$\frac{1}{2}$	.840	.546	.147	2.639	1.715	.554	.234	.320	4.547	6.995	615.017	1.087
$\frac{3}{4}$	1.050	.742	.154	3.299	2.331	.866	.433	.433	3.637	5.147	333.016	1.473
1	1.315	.957	.179	4.131	3.007	1.358	.719	.639	2.904	3.991	200.193	2.171
$1\frac{1}{4}$	1.660	1.278	.191	5.215	4.015	2.164	1.283	.881	2.301	2.988	112.256	2.996
$1\frac{1}{2}$	1.900	1.500	.200	5.969	4.712	2.835	1.767	1.068	2.010	2.546	81.487	3.631
2	2.375	1.939	.218	7.461	6.092	4.430	2.953	1.477	1.608	1.969	48.766	5.022
$2\frac{1}{2}$	2.875	2.323	.276	9.032	7.298	6.492	4.238	2.254	1.328	1.644	33.976	7.661
3	3.500	2.900	.300	10.996	9.111	9.621	6.605	3.016	1.091	1.317	21.801	10.252
$3\frac{1}{2}$	4.000	3.364	.318	12.566	10.568	12.566	8.888	3.678	.954	1.135	16.202	12.505
4	4.500	3.826	.337	14.137	12.020	15.904	11.497	4.407	.848	.998	12.525	14.983
$4\frac{1}{2}$	5.000	4.290	.355	15.708	13.477	19.635	14.455	5.180	.763	.890	9.962	17.611
5	5.563	4.813	.375	17.477	15.120	24.306	18.194	6.112	.686	.793	7.915	20.778
6	6.625	5.761	.432	20.813	18.099	34.472	26.067	8.405	.576	.663	5.524	28.573
7	7.625	6.625	.500	23.955	20.813	45.664	34.472	11.192	.500	.576	4.177	38.048
8	8.625	7.625	.500	27.096	23.955	58.426	45.663	12.763	.442	.500	3.154	43.388
9	9.625	8.625	.500	30.238	27.096	72.760	58.426	14.334	.396	.442	2.464	48.728
10	10.750	9.750	.500	33.772	30.631	90.763	74.662	16.101	.355	.391	1.929	54.735
11	11.750	10.750	.500	36.914	33.772	108.434	90.763	17.671	.325	.355	1.587	60.075
12	12.750	11.750	.500	40.055	36.914	127.676	108.434	19.242	.299	.325	1.328	65.415

to its high cost and difficulty of manufacture without blow-holes and other hidden defects, it is not extensively employed for piping purposes. *Brass* and *copper pipes* are more expensive than mild-steel and wrought-iron pipe, but they with-

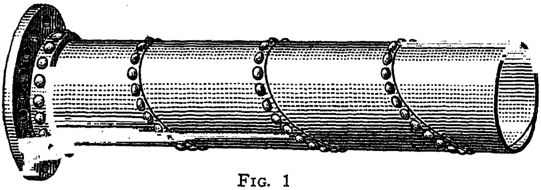
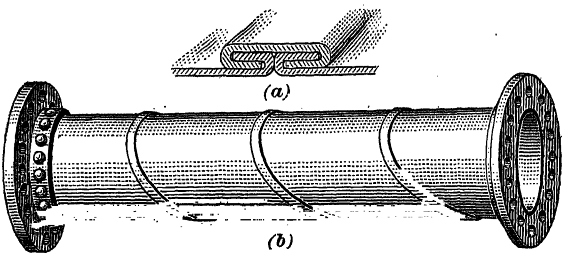


FIG. 1

stand the corrosive action of hot water better than wrought-iron and steel pipe. Owing to their high cost, low tensile strength, and weakness at high temperatures, these materials are not used for piping in high-pressure work to any great extent. They are used for pipe coils in water tanks and in steam tanks or condensers and for boiler connections where there is great liability of corrosion, such as between feed-pumps and boilers. When brass feedwater piping is used, the diameter need not be so large as when extra-heavy steel pipe is used, because there will be no scaling or corrosion to obstruct the flow of water.

5. Galvanized Pipe.—The galvanized pipe used in the smaller sizes is regular wrought-iron or steel pipe coated inside



(a)

(b)

FIG. 2

and outside with zinc. It has the same dimensions as are given in Table I. Galvanized pipe is used for water mains, for underground piping, and where corrosion may occur, as its coating of zinc prevents rapid oxidization or rusting of the

out, the fracture of the metal will show, in the case of wrought-iron pipe, a ragged and fibrous structure, having a dull gray color. In the case of steel the fracture will appear even in texture, having a bright and crystalline appearance; but it develops a dull appearance when exposed to the atmosphere. It will be noted, in threading wrought-iron pipe, that the chips are fibrous and easily break or crumble; but with steel the chip is smooth, tending to curl up and form spirals that are hard and wiry.

6. Spiral Jointed Pipe.—In the manufacture of spiral pipe, strips of steel plate are rolled into a cylindrical pipe as shown in Figs. 1 and 2. The seam may be riveted, as in Fig. 1, or lap-welded; or, a lock seam like that shown in section in Fig. 2 (*a*) may be used. The latter is rolled into a continuous interlocking seam as shown in (*b*). The ends of the pipe are fitted at the factory with cast-iron or steel flanges, which are either welded or riveted to the pipe. Bolt holes are drilled in the flanges so that the pipe sections can be bolted together. The pipes are covered inside and outside with either a zinc coating or an asphaltum paint to protect them from corrosion. They range from 3 to 40 inches in diameter and are cut in lengths up to and including 20 feet. The spiral arrangement of the seam produces a stiff and very strong structure, so that thinner metal can be used than is possible with ordinary riveted or welded pipe. The safe working pressure of spiral pipe is considered to be one-third of the bursting pressure. Spiral pipe is suitable for exhaust steam pipes, water piping, smokestacks, and compressed-air piping. Table IV gives data on the plate thickness and weight of pipe per foot of length, size of flanges, and bursting pressure for spiral pipe.

PIPE FITTINGS

7. Materials for Fittings.—The materials used in the manufacture of pipe fittings are cast iron, cast steel, malleable iron, wrought iron, and brass. Cast iron is used for pipe connections and boiler fittings on pipes for saturated steam, for boiler feedwater piping, and for low-pressure heating work.

10. The pipe union shown in Fig. 5 represents a type that is used in high-pressure steam and hydraulic work for pipes up to 3 inches in diameter. It is made of forged steel throughout and has a **V**-shaped ground joint, as shown at *a*. When the parts *b* and *c* are drawn together by the union ring *d*, the projecting **V** enters the groove in the part *b*, forming a steam-tight metal-to-metal joint along the surfaces *a* and *e*. The slot *f* in the **V**-shaped tongue is to take care of the slight changes due to expansion and contraction caused by variations of temperature in high-pressure work.

11. Flange Unions.—Lengths of pipe may be joined in a continuous line by the use of flange unions such as are shown in Fig. 6. The flanges *a* and *b* are circular metal rings threaded

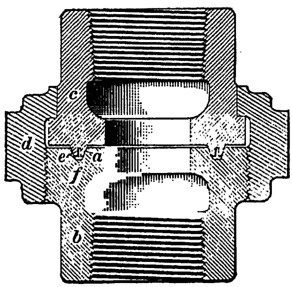


FIG. 5

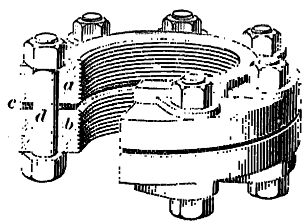


FIG. 6

on the inside so that they may be screwed on the ends of the pipes that are to be joined. The flanges are then brought together, face to face, a gasket *c* is placed between them, the bolts *d* are inserted in holes drilled through the flanges, and the nuts are drawn up. The faces of the flanges are machined and the pipe sections are lined up so that the faces of the flanges are parallel. Compression of the gasket between the flat faces then produces a water-tight or steam-tight joint. Flange unions are made of brass in standard sizes from $\frac{1}{2}$ inch to 6 inches for steam pressures up to 125 pounds per square inch, and extra-heavy flanges are made for pressures up to 250 pounds per square inch. Cast-iron and malleable-iron flange unions may be obtained for pressures up to 250 pounds and for pipe sizes from $\frac{1}{2}$ inch upwards. For very high

and diameter of the flanges, the diameter of bolts and holes, the number and size of bolts, and the diameter of the bolt circles; unless specially ordered otherwise, flanges are generally made according to this standard. This standard was recommended for adoption by a joint committee of the American Society of Mechanical Engineers and the Master Steam Fitters' Association; it is known as the Manufacturers' Standard.

13. Types of Pipe Flanges.—Several types of companion flanges are shown in Fig. 7. The screwed flange in (*a*) is the least expensive style, and is satisfactory for low and medium pressures. The flange is screwed on until the end of the pipe projects through it. Then the end is cut off flush with the face and both are faced so that the surface is square with the center line of the pipe. Sometimes the face of the flange has a number of shallow concentric grooves cut in it, allowing a soft gasket to be used between adjacent flanges without danger of its being blown out. In (*b*) are shown male and female flanges. The male flange *a* has a shoulder that fits into a corresponding recess in the female flange *b*, a gasket *c* being inserted in the recess to make a tight joint. A tongue-and-groove type is shown in (*c*), the tongue *a* on the flange *b* fitting into the groove *c* in the flange *d*, in the bottom of which a gasket is placed. The flanges in (*d*) have raised faces, between which the gasket is held, and recesses are provided at *a* to enable the pipe joints to be calked.

The disadvantages of the types shown in (*b*) and (*c*) are that great care must be taken in manufacture to insure alinement of faces, tongues, and grooves, to prevent subsequent trouble through leaky joints; and if a break occurs in the gasket, the ends of the pipe must be sprung apart to allow a new gasket to be inserted.

Table V shows the dimensions of standard flanges and flange bolts and Table VI gives similar data for extra-heavy flanges. Flanges are designed with an unusually large factor of safety, to cover possible defects in the metal or imperfections in casting. In all cases, it is important that the castings shall be absolutely sound and free from flaws, blowholes, and shrinkage cracks.

will effectively resist a very high temperature. For hydraulic pipe flanges, reinforced rubber packing and composition packing to resist very high water pressures are used.

TABLE VI

DIMENSIONS OF EXTRA-HEAVY THREADED PIPE FLANGES

(For Pressures up to 250 Pounds per Square Inch—Manufacturers' Standard)

Pipe Size Inches	Pipe Flanges			Bolts			
	Outside Diameter Inches	Thickness of Flange Inches	Depth of Thread Inches	Number Required	Diameter Inches	Length Inches	Diameter of Bolt Circle Inches
1	$4\frac{1}{2}$	$\frac{11}{16}$	1	4	$\frac{1}{2}$	2	$3\frac{1}{4}$
$1\frac{1}{4}$	5	$\frac{3}{4}$	$1\frac{1}{8}$	4	$\frac{1}{2}$	$2\frac{1}{4}$	$3\frac{3}{4}$
$1\frac{1}{2}$	6	$\frac{13}{16}$	$1\frac{1}{4}$	4	$\frac{5}{8}$	$2\frac{1}{2}$	$4\frac{1}{2}$
2	$6\frac{1}{2}$	$\frac{7}{8}$	$1\frac{3}{8}$	4	$\frac{5}{8}$	$2\frac{1}{2}$	5
$2\frac{1}{2}$	$7\frac{1}{2}$	1	$1\frac{7}{16}$	4	$\frac{3}{4}$	3	$5\frac{7}{8}$
3	$8\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{9}{16}$	8	$\frac{3}{4}$	$3\frac{1}{4}$	$6\frac{5}{8}$
$3\frac{1}{2}$	9	$1\frac{3}{16}$	$1\frac{5}{8}$	8	$\frac{3}{4}$	$3\frac{1}{4}$	$7\frac{1}{4}$
4	10	$1\frac{1}{4}$	$1\frac{3}{4}$	8	$\frac{3}{4}$	$3\frac{1}{2}$	$7\frac{7}{8}$
$4\frac{1}{2}$	$10\frac{1}{2}$	$1\frac{5}{16}$	$1\frac{13}{16}$	8	$\frac{3}{4}$	$3\frac{1}{2}$	$8\frac{1}{2}$
5	11	$1\frac{3}{8}$	$1\frac{7}{8}$	8	$\frac{3}{4}$	$3\frac{3}{4}$	$9\frac{1}{4}$
6	$12\frac{1}{2}$	$1\frac{7}{16}$	2	12	$\frac{3}{4}$	$3\frac{3}{4}$	$10\frac{5}{8}$
7	14	$1\frac{1}{2}$	$2\frac{1}{16}$	12	$\frac{7}{8}$	4	$11\frac{7}{8}$
8	15	$1\frac{5}{8}$	$2\frac{3}{16}$	12	$\frac{7}{8}$	$4\frac{1}{4}$	13
9	$16\frac{1}{4}$	$1\frac{3}{4}$	$2\frac{1}{4}$	12	1	$4\frac{3}{4}$	14
10	$17\frac{1}{2}$	$1\frac{7}{8}$	$2\frac{3}{8}$	16	1	5	$15\frac{1}{4}$
12	$20\frac{1}{2}$	2	$2\frac{9}{16}$	16	$1\frac{1}{8}$	$5\frac{1}{4}$	$17\frac{3}{4}$
14	23	$2\frac{1}{8}$	$2\frac{11}{16}$	20	$1\frac{1}{8}$	$5\frac{1}{2}$	$20\frac{1}{4}$
15	$24\frac{1}{2}$	$2\frac{3}{16}$	$2\frac{13}{16}$	20	$1\frac{1}{4}$	$5\frac{3}{4}$	$21\frac{1}{2}$
16	$25\frac{1}{2}$	$2\frac{1}{4}$	$2\frac{7}{8}$	20	$1\frac{1}{4}$	6	$22\frac{1}{2}$
18	28	$2\frac{3}{8}$	$3\frac{1}{16}$	24	$1\frac{1}{4}$	$6\frac{1}{4}$	$24\frac{3}{4}$
20	$30\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{1}{4}$	24	$1\frac{3}{8}$	$6\frac{1}{2}$	27
22	33	$2\frac{5}{8}$	$3\frac{7}{16}$	24	$1\frac{1}{2}$	7	$29\frac{1}{4}$
24	36	$2\frac{3}{4}$	$3\frac{5}{8}$	24	$1\frac{5}{8}$	$7\frac{1}{2}$	32

NOTE.—Flanges, flanged fittings, valves, etc. have the bolt holes drilled in multiples of four, so that fittings may be made to face in any quarter and holes straddle the center line.

15. Types of Pipe Joints.—The joints in pipe lines subjected to low pressures may be made with unions like those shown in Figs. 4 to 6; and the screwed flange joint shown in Fig. 7 (*a*) is suitable for pipes carrying saturated steam at or

16. The type of flange shown in Fig. 10 is excellent for high-pressure piping. As indicated in the sectional view (*a*), the flange *a* is shrunk on the end of the pipe *b*. In doing this, the flange is heated so as to cause it to expand, and while hot it is driven over the end of the pipe. When it cools, it shrinks and grips the pipe firmly. The inner edge *c* of the flange is rounded off and the end of the pipe is then peened over by striking it lightly with a hammer, thus giving the flange additional grip on the pipe. Sometimes the security of the fastening is further increased by riveting the pipe to the flange in the manner indicated at *d*. A part of a flange is shown in perspective in (*b*). The bolt holes *a* are formed in bosses *b*, and the spaces between the bosses enable the rivet holes *c* to be drilled and the rivets inserted and headed.

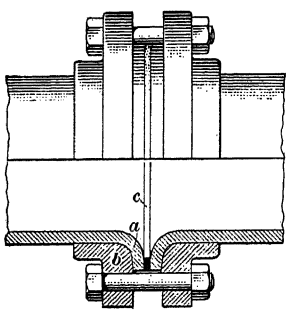


Fig. 11

17. The *Van Stone joint*, shown in Fig. 11, is made by upsetting and flanging the heated end of the pipe *a* over the flange *b*. The face of the flange of the pipe is faced smooth and to a uniform thickness, so as to produce a tight joint and perfect alinement. The edges of the flange are also finished. The flanges *b* are loose on the pipes, being a trifle larger in diameter than the outside diameter of the pipes, and serve as rings that bear on the flanges of the pipes. A gasket *c* is inserted before the flanges are bolted together. When this joint is properly made, it is strong and has no superior for durability. For high pressures, on steam and water lines, forged steel flanges should be employed. Table VII gives the principal dimensions of Van Stone flange connections.

18. A special type of flanged connection is shown in Fig. 12. The flange *a* has a shallow groove *b* on the inner surface, into which the pipe *c* is expanded by rolling under pressure. A recess is cut in the face of the flange *a*, and the end of the pipe is turned out and forced down into this recess, as at *d*, after

bend or break the pipe or its fittings. The linear expansion or contraction of a line of piping may be found by the formula

$$m = C\,l\,t$$

in which m = amount of linear expansion or contraction, in inches;
C = coefficient of linear expansion;
l = length of piping, in inches, before the change of temperature occurs;
t = change of temperature, in degrees Fahrenheit.

The value of C for wrought-iron or steel pipe is .00000599; for cast-iron pipe it is .00000617; and for cast-steel pipe it is .00000636.

EXAMPLE.—A steel pipe line 250 feet long is put up at a temperature of 60° F. When it is finished, superheated steam at a maximum temperature of 370° F. is turned on. Find the linear expansion.

SOLUTION.—Apply the formula just given. The pipe is of steel and so $C = .00000599$; $l = 250 \times 12 = 3{,}000$ in.; and $t = 370 - 60 = 310°$. Substitute these values, and $m = .00000599 \times 3{,}000 \times 310 = 5.57$ in., or $5\frac{9}{16}$ in., nearly. Ans.

20. Expansion Joints.—The example of the preceding article shows that the change of length of a straight pipe

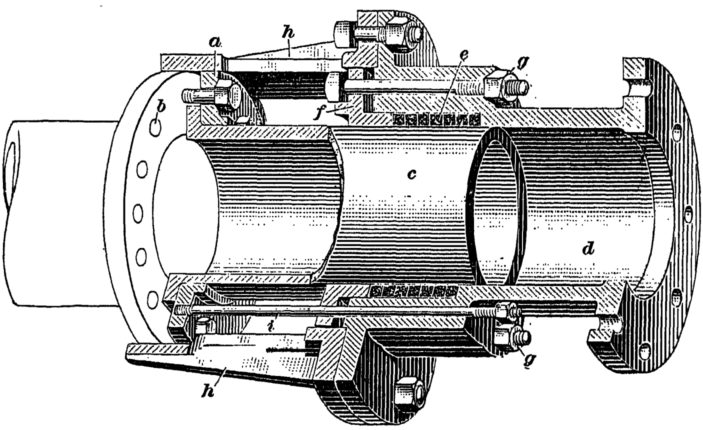


FIG. 13

line, under change of temperature, may amount to several inches. One way of preventing damage to the pipe and fittings

section *b*. A stuffingbox *c* maintains a steam-tight joint between the two. The method of installing this joint is shown in (*b*). The sections *a* and *b* of the main steam piping are not in a straight line, but are offset. They are connected by elbows to the swivel expansion joints *c* and *d*, these being joined by the pipe *e* and connecting elbows. Thus, any change of length of the pipes *a* and *b* simply causes swiveling of the expansion joints and prevents stresses from being set up in the piping.

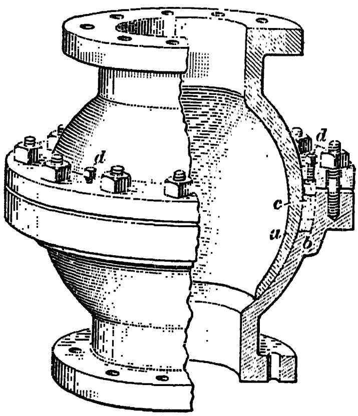


FIG. 15

A flexible joint is shown in Fig. 15. The section *a* and the section *b* into which it fits are made spherical, and a stuffingbox is provided to form a tight joint between them. The packing *c* is compressed by turning the setscrews *d*. The section *a* can move in any direction sidewise. This type of joint is made in standard and extra-heavy styles to carry pressures up to 250 pounds per square inch.

22. Damage through change of length of straight piping may be provided against by inserting a section of corrugated piping, such a section being called a corrugated expansion joint. A joint of this kind is illustrated in Fig. 16, the material of which it is made usually being copper. The elasticity of the section, due to the corrugations, allows it to be compressed or drawn out to some extent, and so it takes up expansion or contraction of the pipe line in which it is inserted. The corrugations are rolled into the sheet from which the pipe is made. The form shown is used principally

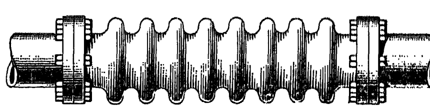


FIG. 16

on exhaust-steam lines. Another form, in which iron or steel rings are used to reinforce the corrugated section and yet not interfere with its axial lengthening and shortening, is used in high-pressure work.

23. Pipe Bends.—An excellent way of allowing for expansion and contraction of pipe lines is to use pipe bends, as shown in Fig. 17. The forms of bends illustrated are used extensively on long pipe lines as well as on steam-engine connections and other piping subjected to considerable vibration. Wrought-pipe bends are made while the material is red hot. The radius r of the bend must be large, so as to give the proper spring to the bend and to reduce as much as possible the friction of the steam in flowing through it.

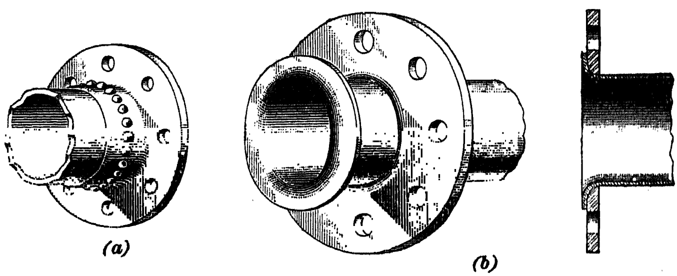


FIG. 18

The larger the radius, the more fully these objects are attained. Generally, the radius should not be less than six times the diameter of the pipe. The bends are connected to other pipes by extra-heavy flanges of cast steel, forged steel, or malleable iron, these being fastened to the bends by one or other of the methods previously illustrated. A short section a of each bend, near the flange, is left straight, so that the flange will stand square with the axis of the adjoining section of pipe. In large bends, as, for example, the double-offset expansion **U** bend, the fitting is made in three sections, flanges being used at b to connect them.

Pipe bends made of copper pipe may have shorter radii, as copper is more ductile than steel and yields more readily to the bending operation without undue buckling. Small sizes

sections of different sizes to fit pipes of different diameters. The sections are split lengthwise, so that they may be placed over the pipe, and are held together by a canvas jacket that may be painted or tarred to resist the weather. Polished and lacquered brass bands are also used to hold the sections in place on the pipe. Charcoal, slacked lime, and sawdust are inexpensive materials that may be placed around pipes laid in trenches.

25. Pipe Supports.—Great care must be exercised in hanging and supporting steam piping so as to take care of

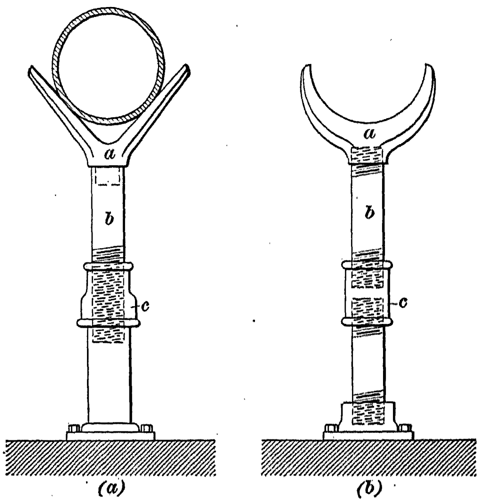


FIG. 20

the movement of the pipes due to expansion and contraction, to keep the pipe sections in proper alinement, and to provide for a rise or fall in the steam line so that the water formed by the condensation of steam will not flow back toward the boiler, in opposition to the direction of flow of the steam. The style of support will vary according to the piping arrangement. Pipe supports in general are standardized and may be classified as *hangers*, *standards*, and *brackets*. Hangers, shown in Fig. 19, carry the pipe overhead and are attached to rafters or other structural members in the frame of the

bracket *a* is a frame *b* that carries a roller *c*. For long piping of large diameter, the bracket shown in (*b*) is equipped with an upper roller *d*, which assists in maintaining proper alinement of the piping. To take care of the expansion of the pipe, and

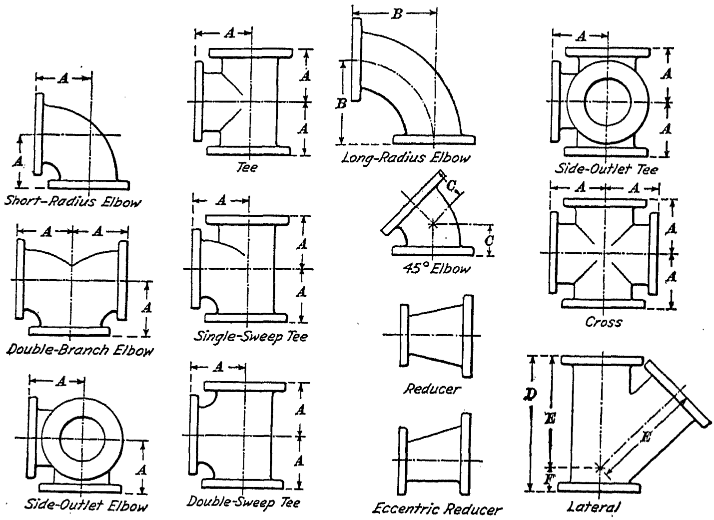


FIG. 22

at the same time hold the roller in position, springs *e* are installed at the bottom of the support rods for the upper roller.

27. Flanged Fittings.—American standard flanged fittings for the several classes of pipe are of the forms shown in Fig. 22. For standard pipe the face of the flange is plain, but the extra-heavy flange has a shoulder $\frac{1}{16}$ inch high, as shown in section in Fig. 23. These fittings are employed in making bolted pipe connections, where it is necessary to run the piping in different directions. The dimensions of the different flanges for pressures up to 125 pounds per square inch are given in Table VIII. The reference letters in Fig. 22 indicate the respective dimensions and correspond with those given in the table. Similar data for extra-heavy flanged fittings,

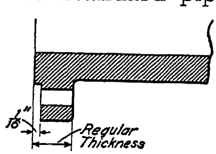


FIG. 23

carrying pressures from 125 to 250 pounds per square inch, are given in Table IX. The diameters of the flange and of the bolt circle, the thickness of the flange, and the number of bolt holes, for both standard and extra-heavy flanged fittings, are the same as for the corresponding sizes of companion flanges, and are given in Tables V and VI. Where it is necessary to run two pipes of different sizes from the same flanged fitting, a reducing tee, cross, or lateral is employed. The usual forms of these fittings are illustrated in Fig. 24. Flanged fittings may be made of cast iron, cast steel, or malleable iron.

28. Standard screwed fittings, such as tees, elbows, and laterals, are made for the smaller sizes of piping, and can be obtained in many different forms, threaded with right-hand

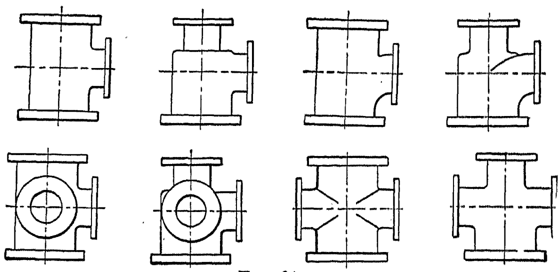


FIG. 24

threads. The size of a tee is designated by first stating the size of the run and then the size of the branch. The *run* is the line of pipe that enters and leaves the tee in the same straight line. Thus, the tee in Fig. 25 (*a*) has a 2-inch run and a $1\frac{1}{2}$-inch branch, and would be called a $2'' \times 1\frac{1}{2}''$ tee. If all the outlets of the tee had been for 2-inch pipe, it would have been termed a straight $2'' \times 2''$ tee, or simply a straight 2-inch tee. The tee shown in (*b*) connects pipes of three different diameters and is called a *reducing tee*. It is designated as a $1\frac{1}{2}'' \times 1\frac{1}{4}'' \times 1''$ reducing tee, the numbers being given in the order of their size, the largest first.

29. A lateral, or **Y**, having a branch at an angle of 45°, is shown in Fig. 25 (*c*). The method of designating the size of a lateral is the same as for a tee; thus, the lateral shown would

or left-hand threads; or, the ends may be threaded in opposite directions. Reducing ells, of the type shown in (*e*), and, in fact, all other reducing fittings, have right-hand threads only.

VALVES AND COCKS

30. Globe Valves.—Valves are used to control the flow of water and steam in boiler piping. The bodies may be made of brass or iron, but the valve disks and seats are of composition

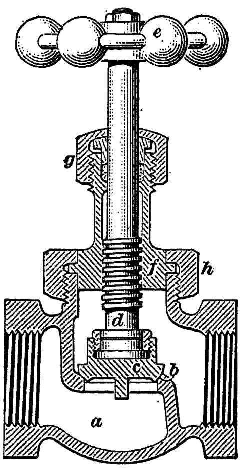


Fig. 26

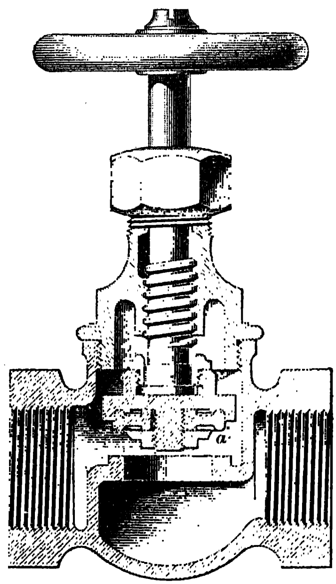


Fig. 27

metal. The working pressure and the kind of service determine the weight, size, and design of valve to be used. A sectional view of a globe valve such as is used on steam piping is shown in Fig. 26. The body *a* and the partition in which the seat *b* is formed are cast in one piece. The seat *b* is ground to a bevel to match the bevel of the valve disk *c*, which is fastened to the lower end of a threaded stem *d* carrying a hand wheel *e*. The threaded stem fits in a nut *f*, in the upper

The seat *c* is placed directly in the inlet opening, and as there are fewer changes of direction of the fluid passing through the valve, it offers less resistance to flow than does the globe valve shown in Fig. 26. Because the valve stem is long, a guide is provided in the form of a spindle *d* held in the spider *e*. The valve disk *f* is faced with brass. This valve is intended for large pipes that carry pressures of from 125 to 250 pounds per square inch.

33. Gate Valves.—Gate valves are made either as *single-gate valves*, which receive pressure on one side only, or as

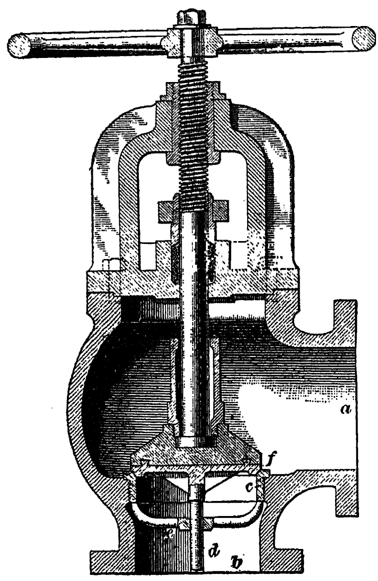


FIG. 29

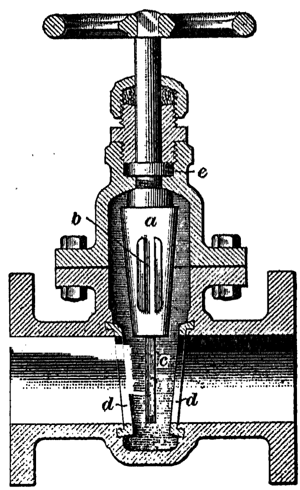


FIG. 30

double-gate valves, which may receive pressure on either side. Some forms of double-gate valves close the opening of the valve with a solid wedge; others close with a box wedge, and others with sectional gates having either parallel or wedge-shaped seats.

Gate valves are advantageous where little resistance to the flow of the liquid is desired, as they leave an unobstructed

of this type are that the extension of the stem shows the position of the gate, and that the screw can always be properly lubricated and does not come in contact with the steam.

By-passes are desirable on or around all live-steam valves of 6 inches and upwards. Fig. 32 shows a gate valve provided with a small by-pass valve *a*. By first opening the small valve, the pressures on the two sides of the disk are equalized, thus making the valve easy to open.

Gate valves should be installed in a vertical position, so that the regulating spindle is upright and the hand wheel on top. The valve should never be placed so that the hand wheel is on the bottom, because, when the gate is partly opened, a pocket is formed and the steam and water have a tendency to follow along the spindle and drip.

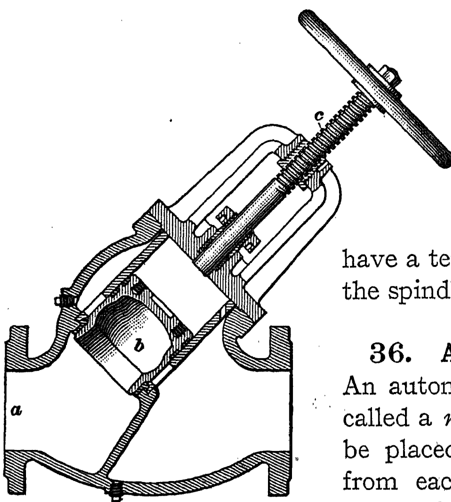


Fig. 33

36. Automatic Stop-Valve.—An automatic stop-valve, often called a *non-return valve*, should be placed in the pipe leading from each boiler to the main steam pipe, when two or more boilers are connected in a battery. If one of the boilers becomes sluggish in generating steam, its stop-valve will close automatically and will remain closed until the pressure in the sluggish boiler has been built up to that existing in the main, when the valve will open. Such a valve is a protection against accidents. If one of a battery of boilers has a blown-out tube, or any other mishap that suddenly lowers the pressure, the stop-valve closes and prevents the steam from backing into the damaged boiler from the main pipe. If a boiler is undergoing repairs, the presence of such a valve on its steam line is a safeguard

38. The check-valve shown in Fig. 34, known as a *swing check-valve*, may be used in either a horizontal or a vertical pipe. The valve disk *a* is attached to an arm *b* hinged at *c*. The disk and arm are so connected as to permit a slight movement of the disk so that it will close on the seat *d* properly. The lug *e* on the arm strikes the screw *f* when the disk is swung open, thus preventing it from swinging too far. The screw cap *g* covers the opening that gives access to the valve for inspection. The direction of flow of the fluid is indicated by the arrows. This type of check-valve probably offers less resistance to the passage of a fluid than any other form.

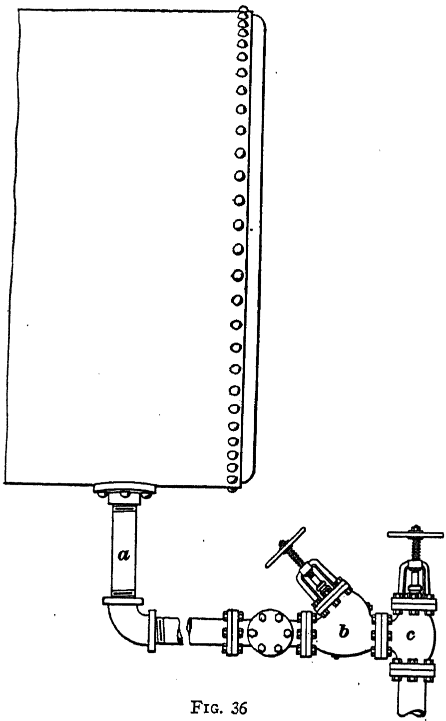


FIG. 36

39. In Fig. 35 is shown a *globe check-valve*, the form most commonly used. The disk *a* is provided with wings *b* on the bottom and a guide *c* on the top to keep the valve from tilting sidewise. Special forms of these types of valves are made to take the place of elbows in pipes. In such cases, they are known as *angle check-valves*.

40. Blow-Off Valves and Cocks.—The blow-off pipe is connected to the bottom of the boiler or mud-drum, or at the lowest part of the water space. Its purpose is to drain the boiler, as well as to remove scale, mud, and other sediment that collect at the bottom of the boiler. The blow-off con-

in diameter and the maximum not over $2\frac{1}{2}$ inches in diameter. No reducing fittings are permitted in the line, as the piping must run full size its entire length. A blow-off valve or cock must be absolutely tight to prevent leakage, and should also be capable of being opened and closed easily. It must also be constructed of materials that will withstand the severe service to which it is subjected. Ordinary steam globe valves are not suitable for connections of this kind.

42. A very good form of angle blow-off valve is shown in Fig. 37. The body *a* and yoke *b* are made of iron, and the working parts, such as the valve stem *c*, the valve disk *d*, the valve seat *e*, and the bushings *f*, are made of bronze. In the valve disk *d* are seating surfaces *g* made of an alloy that, being softer than the valve seat, will yield to any irregularities and make a tight connection. At the back of the valve is a clean-out plug *h*, which is removable, permitting the insertion of a rod into the valve for clearing away sediment, scale, etc. that may accumulate in the inlet *i*. All angle valves should be connected so that the inlet or side opening *i* is toward the boiler and thus have the pressure on top of the valve disk. This arrangement protects the valve disk and the valve seat from the direct impact of the steam and sediment. The valve should be opened wide when the boiler is blown down, so as to reduce as much as possible the wear on the seat and disk.

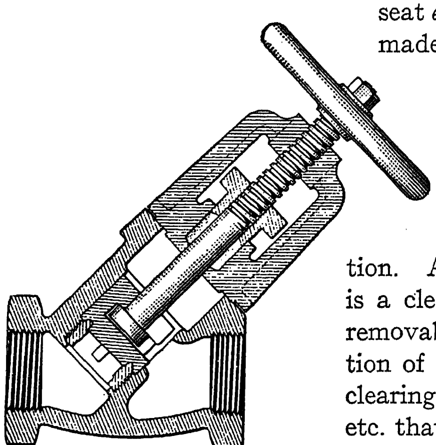


Fig. 38

The **Y** blow-off valve, Fig. 38, is sometimes placed in the run of piping between the boiler and the angle blow-off valve, as shown at *b*, Fig. 36. The valve shown in Fig. 38 is of special design, and constructed of a hard, non-corroding

and makes a tight joint, and at the same time allows the plug b to be turned easily. For a top packing a vulcanized composition ring is used. The form of the asbestos packing contained in the **U** grooves is shown in (b). Since the asbestos is not affected by heat or moisture, this form of cock is durable. In blowing down a boiler the **Y** valve or blow-off cock is opened first, and then the angle blow-off valve. After the boiler is blown down, the angle valve is closed first, and then the **Y** valve or blow-off cock.

45. Pressure-Reducing Valves.—When steam is required at a lower pressure than that at which it is supplied by the boiler, some form of pressure-reducing valve must be used. A reducing valve, designed to give a uniform low pressure from a varying higher pressure, is shown in Fig. 41. The steam flows through the valve from the inlet a to the outlet b, as shown by the arrows. When it is desired to use it as an angle valve, the outlet may be made at c. The flow of the steam is impeded and its pressure reduced by means of two disks d and e covering the ports in the interior of the valve body. These disks are connected by the sleeve f and are rigidly attached to the valve stem, so that the ports are opened by the downward movement of the valve stem and closed by the upward movement. Each disk is guided by four wings on its upper side, and by the valve stem, which passes through a hole in the bonnet h.

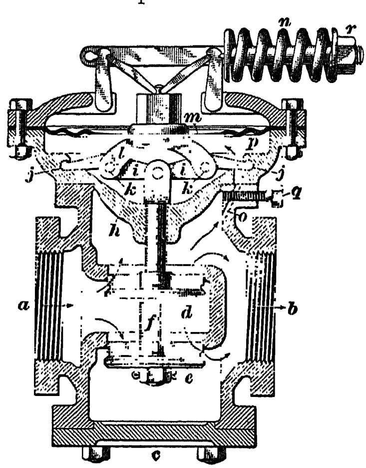


Fig. 41

46. The upper end of the stem, Fig. 41, is connected to the inner ends of two levers i that have their fulcrums j in the flange of the bonnet. The levers are pivoted on pin connections k in the ends of a yoke l. The yoke is attached to the

steam is given a whirling motion, so that the water held in suspension in the steam is thrown outwards by centrifugal force against the walls of the separator. In a baffle-plate separator the steam comes in contact with plates generally placed at right angles to the direction of flow of the steam. The plates abruptly change the direction of the steam current. Either type of separator causes the particles of water to be thrown out of the steam current, and on striking the walls of the separator, the water is led away to a drain. The dry steam passes through the separator to the main piping.

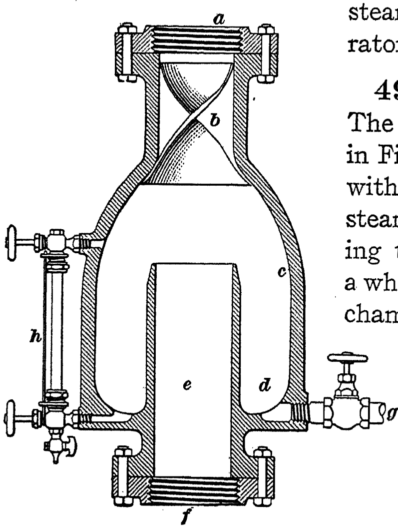


FIG. 43

49. Centrifugal Separator. The centrifugal separator shown in Fig. 42 is arranged to connect with horizontal piping. The steam enters at *a*, and on striking the curved baffle *b* is given a whirling motion as it enters the chamber *c*. The particles of water are thrown off by the centrifugal action, run down the walls of the separator, and collect in the chamber *d*. The steam current is reversed, flows over the edge of the projecting pipe *e*, and escapes at *f*. A gauge glass *g* is provided to show the amount of water that has collected, and a drain pipe *h* to remove the water.

50. The vertical centrifugal separator shown in Fig. 43 operates like the horizontal type. The flange *a* is connected to the boiler side of the vertical piping. The steam flows down over the baffle *b*, by which it is given a whirling motion. The whirling of the descending current throws the particles of moisture outwards against the wall *c* of the separator, from which they trickle down and collect in the chamber *d*. The steam escapes by way of the passage *e* to a pipe connected at *f*.

ings. Such devices also serve as mufflers, deadening the sound of the exhaust. Exhaust heads are made of steel plate or cast iron, that shown in Fig. 46 being a typical steel exhaust head. The exhaust steam enters at *a* and travels in the direction of the arrow until it strikes the inverted conical surface *b* and the walls of the cylinder *c*. A drip through *d* around the base of the cylinder *c* collects the water that flows down its surface.

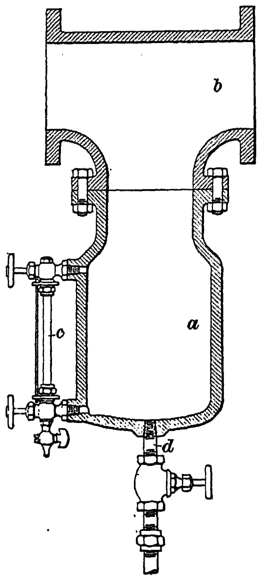


FIG. 45

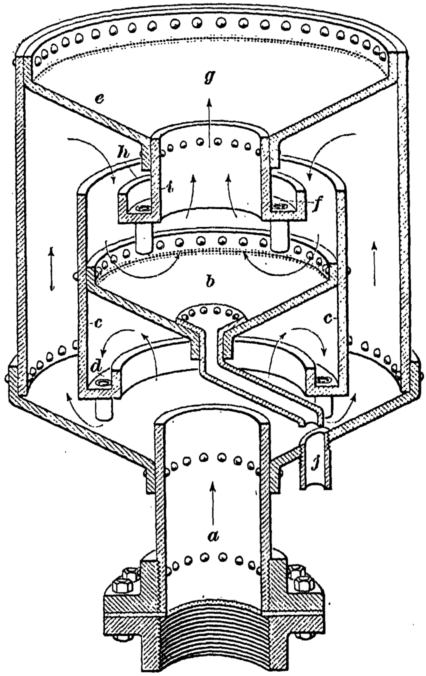


FIG. 46

The steam flows down and out at the bottom of the cylinder *c* and rises until it strikes a second inverted cone *e*, on which it deposits additional water. This water follows the surface of the cone and drips into the trough or gutter *f*. The steam passes out at *g* to the atmosphere after flowing over the top edge of the cylinder *c*, past the lip *h*, and up through the cylinder *i*. Drip pipes installed at the bottoms of the gutters carry the water to the outlet *j*, thus draining the water from the exhaust head.

from the trap. As the condensation collects in the body of the trap, the empty bucket tends to float and swings upwards on its pin *e*, thus forcing the valve *g* against its seat and closing the outlet. The condensation accumulates and eventually spills over the edge of the bucket and collects in the bucket, which promptly sinks and opens the valve *g*. The interior of the trap is subject to the pressure existing in the steam pipe, and this pressure forces the water inside the bucket to flow up inside the sleeve *i*, through the opening *h*

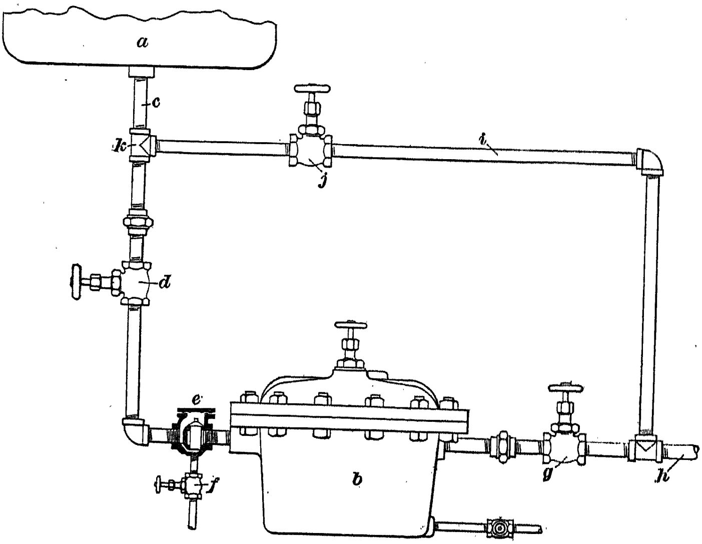


FIG. 48

and out through the discharge at *j*. When the bucket is nearly emptied, its buoyancy causes it to float, and in rising it again closes the valve *g* and prevents the escape of steam.

57. Steam-Trap Connections.—An example of the way in which a steam trap may be connected is shown in Fig. 48. The condensation from the steam pipe runs into a drip pocket *a*, from which it drains into the steam trap *b* through a pipe *c*, valve *d*, and strainer *e*. The strainer prevents the entrance of anything that might clog the trap. It may be flushed out by opening the valve *f*. On the discharge side of the trap is a

of condensation to flow into the boiler. One form of return trap, known as a tilting trap, with the necessary piping and valves to connect it to a boiler, is shown in Fig. 49. It consists of a cast-iron receiver *a* supported at one end by hollow trunnions *b* and *c* on the stationary part of the trap and at the other end by a link, a lever, and a weight *g*. In the drainage of a heating or steam-pipe system, the different return pipes lead to a tank, as shown at *d*. The water rises through the pipe *e*, and passes through the check-valve *f* and trunnion *c* to the receiver *a*. The water enters this receiver until its weight is sufficient to overbalance the counterweight *g*, when the receiver *a* moves downwards until it comes against the guide *h*. This downward motion causes the lug *i* to engage the upper nuts on the stem of the steam valve *j*, opening the latter and thus admitting steam at full boiler pressure on top of the water. Steam enters from the boiler through the pipe *k*, trunnion *b*, and curved pipe *l*, leading to the highest point in the receiver. Driven by the steam, the water flows from the receiver to the boiler by gravity, through the trunnion *c*, check-valve *m*, pipe *n*, and globe valve *o*. As soon as the receiver is emptied, the weight *g* lifts it to its upper position, which closes the steam valve *j* and opens a small air valve *p* below the valve *j*, allowing the steam to exhaust from the receiver. A cock *q* is provided on the trunnion *b* for the purpose of venting the interior of the receiver by hand, if necessary at any time.

59. When there is not sufficient pressure to make the water in the receiver enter the trap on top of the boiler, another trap may be placed at the point where water will flow into it. This trap may then be made to discharge into one placed on top of the boiler, using steam from the boiler as a motive force.

Return traps can be made to discharge the water into elevated tanks, the height to which the water may be raised depending on the available boiler pressure. This height, in feet, allowing for frictional and other resistances, is given approximately by multiplying the boiler pressure available by 1.4. Thus, if the boiler pressure is 60 pounds per square inch, a return trap can discharge into a tank $60 \times 1.4 = 84$ feet above it.

under the effect of heating and cooling. One form is shown in Fig. 51. The condensation enters by way of the pipe *a*, flows past the valve *b*, and collects in the chamber *c*, which contains an air-tight circular vessel *d* made of thin sheet metal. The water escapes from the chamber *c* through the outlet *e*. When most of it has escaped, and hot water or steam enters the chamber *c*, the heat causes the air in the vessel *d* to expand, and the flat sides bulge out, as indicated by the dotted lines. The valve *b* is pushed against its seat by this bulging of the vessel *d*, and the flow is stopped until the collected water cools and the vessel *d* contracts enough to open the valve. With a uniform rate of condensation, the action of the trap is practically continuous. A dirt pocket is provided at *f*, and an adjusting screw at *g* to alter the quickness with which the valve is closed. The thermostatic trap is not likely to freeze or become air-bound.

62. Suggestions for Trap Installations.—The size of trap to be used depends on the volume of water of condensation to be handled and is not based on the size of the pipe to which it is attached. There are several rules to be followed in the installation of a trap: The trap must be located at a low point in the return piping, so that the water of condensation will flow to it by gravity. Means must be taken to prevent the trap and piping from freezing; for, when a trap is blocked with ice, the valves will not work and the water will back up in the return piping. By-pass piping should be so installed that, in case the trap must be cleaned or repaired, the condensation may be discharged through the by-pass.

DESIGN AND ARRANGEMENT OF PIPING

PRINCIPLES OF DESIGN

63. General Requirements.—The installation of a complete steam plant includes the setting of the boiler or boilers, the arrangement of the various lines of piping, and the location and arrangement of the various accessories, such as feedwater heaters, purifiers, separators, economizers, feed-pumps, and

from the steam, and, by suitable traps or return systems, delivered again to the boiler. Drainage is best effected by arranging the piping so that all the water of condensation will flow by gravity toward a point close to the delivery end of the pipe, and then providing a drip pipe at that point. In the case of large pipes, a trap may be placed at the end of the drip pipe for automatic draining; the trap serves to seal the end of the drip pipe and thus prevents waste of steam.

66. Water Hammer.—The presence of water in a steam pipe is the cause of water hammer, the term used to describe the condition that causes the hammering noise often heard in the piping of steam-heating plants. It has been shown experimentally that the pressure produced by water hammer may be as great as ten times that which the pipe is expected to sustain in its regular work. In some cases, water hammer has caused boiler explosions by bursting a steam pipe and thus relieving the boiler pressure so suddenly that a large quantity of water flashed into steam.

67. Condensation and Friction.—When steam leaves the boiler and flows through a pipe to the point where it is to be used, it loses a part of its original energy. Some of its heat is lost by radiation, conduction, and convection, and if the steam is not superheated, this loss of heat results in condensation of part of the steam. It takes place whether the steam is flowing or at rest, but it may be reduced to a minimum by using non-conducting coverings on the pipes.

Because of friction in flowing through pipes and fittings, the pressure of steam at the outlet, or discharge, end of a system of piping is less than at the inlet, or boiler, end. The loss of pressure due to friction reduces the flow below the estimated capacity of a straight pipe, and must be taken into account in the case of a long pipe with numerous bends and fittings.

Friction is greater through elbows of short radius than through elbows of long radius, because the change of direction of flow is more abrupt. It is advantageous, therefore, to make all bends of large radius. Globe valves offer considerable

length of pipe rises vertically above the shell of the boiler and connects with a bent branch pipe joined to the main steam pipe or header, the bent pipe allowing the header to expand and contract freely. In (*b*), connection between the boiler end and the header is made by using a **U** bend; and (*d*) illustrates the use of two quarter-turn bends in making the connection. It is generally conceded that, when pipe bends are thus used, the best position for the valve, when only one is used, is at the center of the bend; but some engineers regard

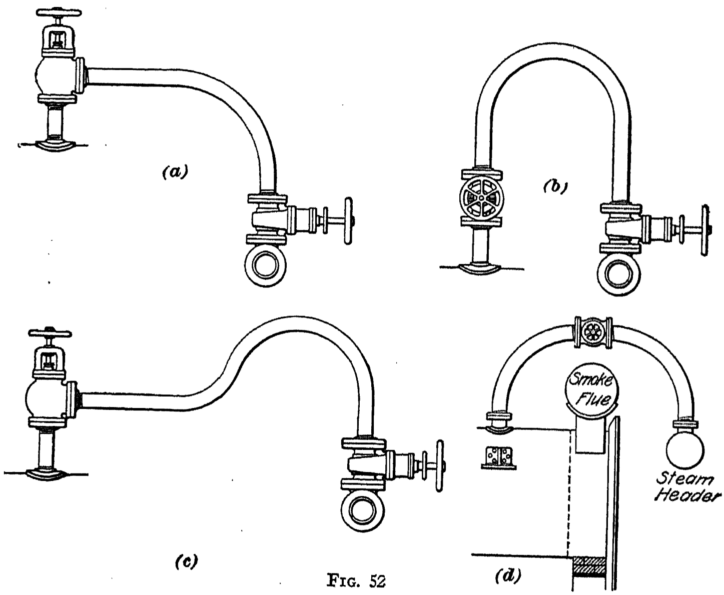


Fig. 52

it as better practice to use two valves, one being placed near the main and the other at the boiler. When two valves are used, it is frequently necessary to tap the body of each valve for a drip connection to drain away any water of condensation that may accumulate in it.

71. In Fig. 53, in which a straight pipe *a* is used, the length of the vertical sections should be great enough to give the spring necessary to allow for expansion without straining any of the pipe parts and fittings. The branch pipe *b* is the

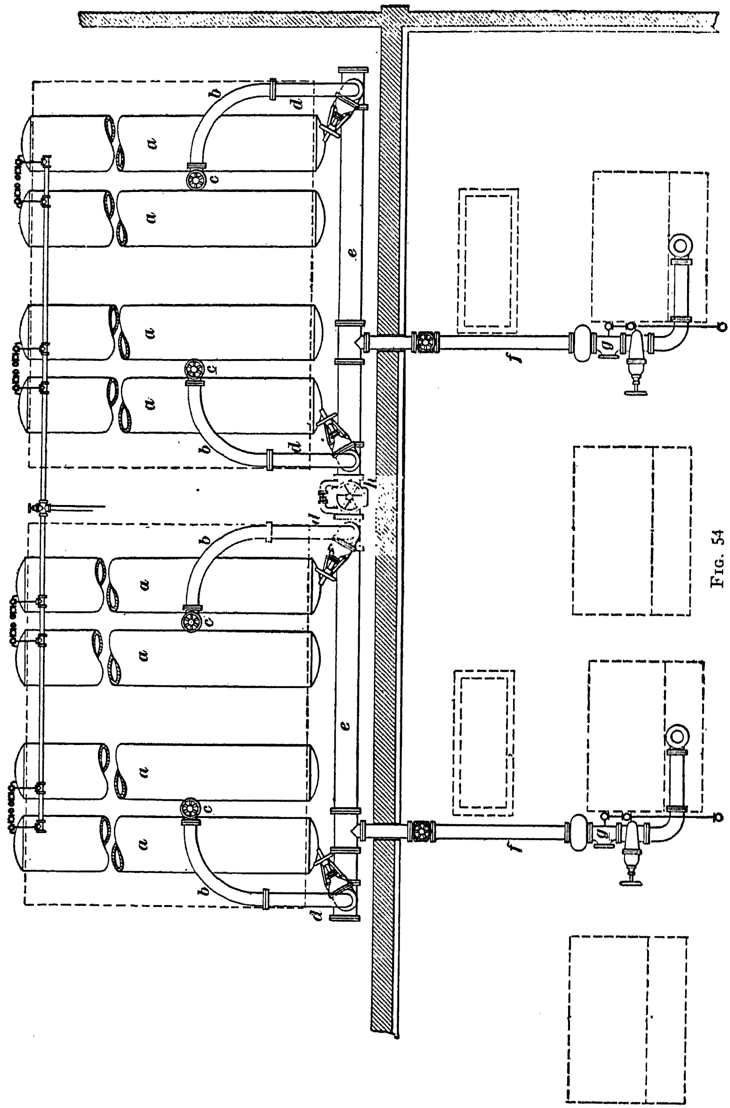


Fig. 54

to the live-steam header *e*. This arrangement gives great elasticity to a system of large piping, and the valves are in convenient positions for ready manipulation.

74. Only the main steam piping is shown in Figs. 54 to 56, the auxiliary piping for the boiler, feedwater heaters, etc. being omitted. Fig. 54 is a plan view, Fig. 55 an end view, and Fig. 56 a view showing the arrangement of the main steam pipes looking toward the rear of the boilers. The steam pipes *f*, running from the header *e* to the high-pressure cylinders of the steam engines, are placed under the engine-room floor, and a connection to the low-pressure cylinder is provided at *g*, so that in case of emergency the low-pressure cylinder can be run with high-pressure steam. By examining the arrangement of valves between the boilers and engines, it will be seen that without duplicate piping it is possible to cut out any engine or boiler in case of accident and still run the plant with the remaining engines and boilers. The main steam header is divided into two sections by the large gate valve *h*, Figs. 54 and 56, so that one half of the header can be cut off from the other half by closing the valve.

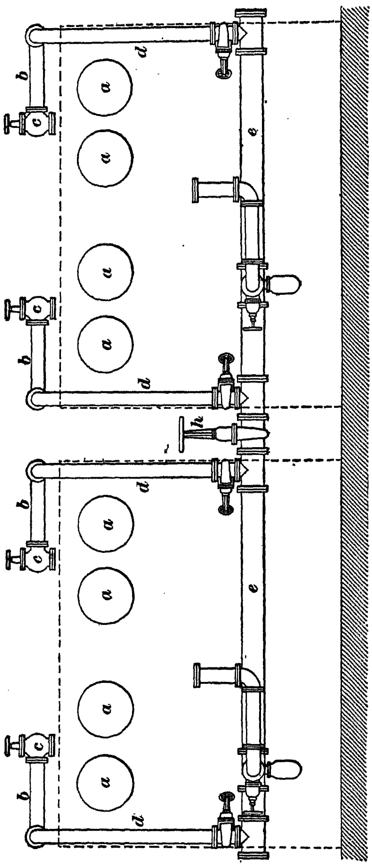
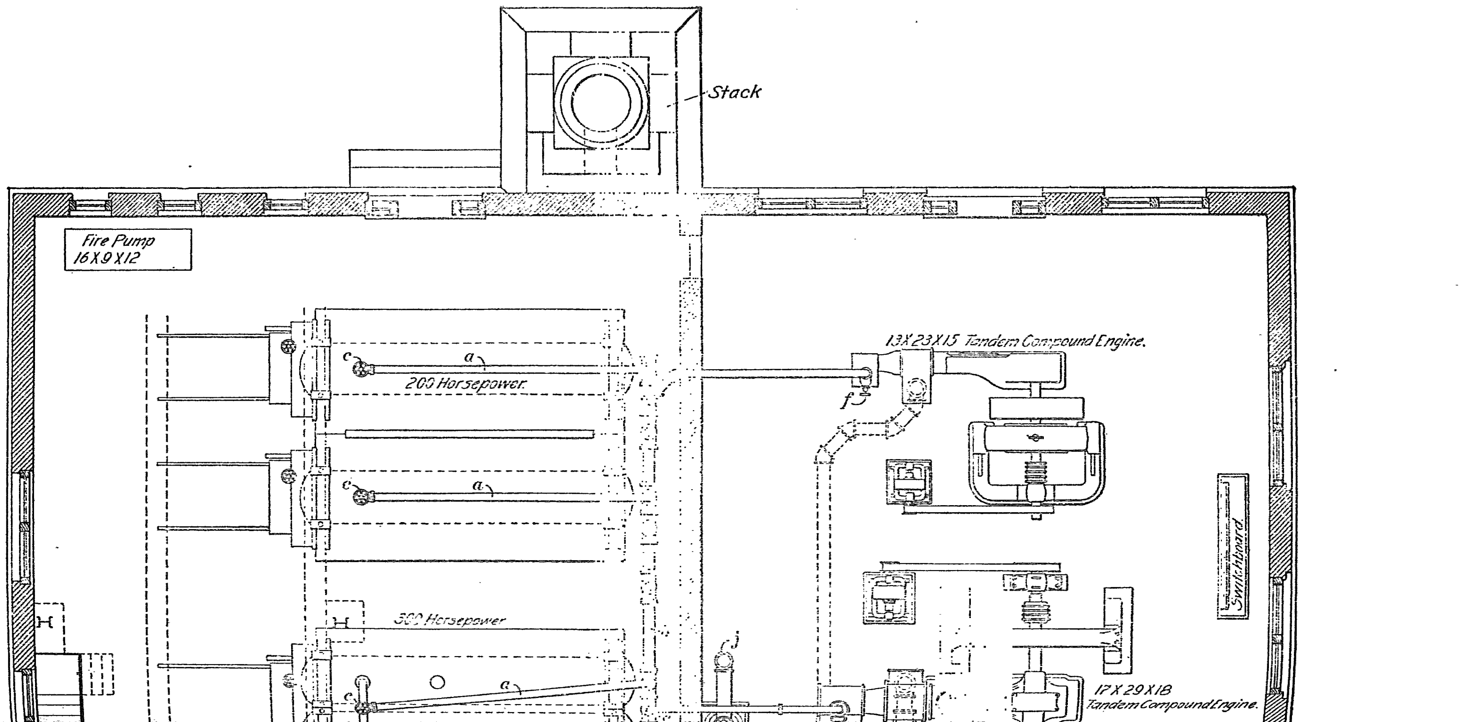


Fig. 56


Stack
Fire Pump
16 X 9 X 12
13 X 23 X 15 Tandem Compound Engine.
200 Horsepower.
300 Horsepower
Switchboard.
17 X 29 X 18
Tandem Compound Engine.
a
a
a
c
c
c
f
j

prime movers, such as turbines or engines, or with pumps. The single-pipe system has a disadvantage in that a break in the main steam piping, although the piping is divided by valves, necessitates the closing down of a part of the plant until repairs can be made. However, if any of the boilers or prime movers are disabled, it is possible to place the unit out of commission for repairs by closing the valves in the piping leading to and from that unit. An auxiliary feedwater system should be installed to provide additional means for feeding water to the boilers in case the main feed supply is temporarily disabled. The single-pipe system is not suitable for very large power

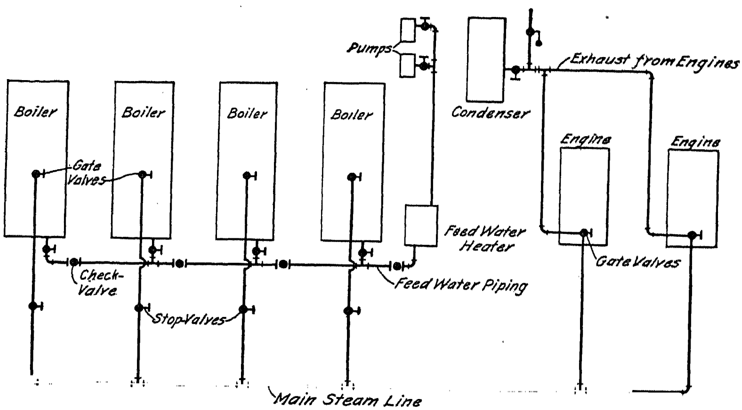


FIG. 58

plants, especially such plants as generate electricity for railways, lighting systems, and other purposes for which continuous service at full-load capacity is required.

78. **Double-Pipe System.**—The double-pipe system, or duplicate system, consists in connecting each boiler and prime mover with a double-pipe header and valves. The arrangement of piping and valves for such an installation is shown in Fig. 59. The cost of installation is greater than the single-pipe method, but this is offset by the greater reliability, as it insures continued service in the power plant. The main objection to the double-pipe system is that the colder pipes in the steam headers will be affected by the stresses arising from

the expansion of the active steam piping, thus causing conditions that are liable to produce leaky pipe joints. This trouble may be avoided by using long lines of piping and long-radius bends that will be sufficiently flexible to reduce the stresses on the pipe joints. Steam headers made in the form of loops are better adapted to take care of the expansion and contraction stresses. For large power plants, an auxiliary set of boilers and some prime mover units are included in the power equipment, thus involving an adequate piping system based on the principles applied in the double-pipe arrangement.

PIPE CALCULATIONS

STEAM-PIPE SIZES

79. Flow of Steam in Pipes.—Steam flows through a pipe because the pressure is higher at one end than at the other. The greater the difference of pressure at the ends, the faster will be the flow, and the greater will be the weight of steam delivered in a given time. The greater the velocity of flow of the steam, the smaller will be the diameter of the pipe for a given discharge of steam; thus, it is advantageous to have the steam travel rapidly, as the cost of pipe is reduced. Besides, a small pipe has less exposed surface than a large pipe, and so the heat loss from it will be less. On the other hand, the friction increases as the diameter of the pipe is reduced, and it increases as the square of the velocity; that is, if the velocity of flow of steam is made twice as great, the friction becomes about four times as great. The effect of this friction is to reduce the pressure at the discharge end, or to cause what is commonly called a drop of pressure. The drop of pressure increases at the same rate as the length of pipe increases, and is proportional to the weight per cubic foot of the steam, or the density of the steam. Thus, the problem of finding the size of steam pipe for a given service involves a compromise between a reasonable drop of pressure and as small a pipe as can feasibly be used.

Solution.—A discharge of 2,800 lb. per hr. is equivalent to 2,800 $\div(60\times 60)=.78$ lb. per sec. This is the required capacity of the pipe. According to the example, $p=2$ lb. and $L=160$ ft. The weight of a cubic foot of saturated steam at 200 lb., gauge, or 215 lb., absolute, according to the Steam Table, is $w=.468$ lb. For a trial solution, assume a 2-in. pipe. The corresponding value of C, from Table X, is 5.1. Substitute these values in the formula, and

$$W=5.1\sqrt{\frac{3\times .468}{160}}=.48 \text{ lb. per sec.}$$

As the pipe must discharge at least .78 lb. per sec., it is plain that a 2-in. pipe is too small. So, try a $2\frac{1}{2}$-in. size, for which the value of C is 8.5, and again substitute in the formula. Then,

$$W=8.5\sqrt{\frac{3\times .468}{160}}=.8 \text{ lb. per sec.}$$

This is only slightly greater than the required discharge, and so a $2\frac{1}{2}$-in. pipe will be satisfactory. Ans.

81. Velocity of Steam in Pipes.—The pipe sizes used in connection with the transmission of saturated steam are such as to give steam velocities of from 3,500 to 6,000 feet per minute in the pipes. In the case of superheated steam, velocities of 12,000 feet per minute, or higher, are possible, because the weight of a cubic foot of superheated steam is less than that of a cubic foot of saturated steam at the same pressure. In reality, the velocity of flow is of no particular consequence, so long as the required capacity can be obtained without exceeding the allowable drop of pressure. The allowable drop of pressure may be from 1 to 5 pounds per 100 feet of length of pipe.

82. Supply Pipes for Steam Engines.—In the case of a pipe supplying steam to a turbine, the flow of steam is continuous; but if a reciprocating engine is used, steam flows into the engine cylinder during only a part of each stroke, so that the flow in the pipe is intermittent, rather than continuous. This point should be considered in calculating the size of a pipe to supply steam to a reciprocating engine. Suppose, for example, that an engine that cuts off at one-fourth stroke requires 3,600 pounds of steam per hour. As steam flows into the cylinder during only one-fourth of each stroke, the

elbow is assumed to be approximately equal to two-thirds that of a globe valve. It is assumed that the resistance at the entrance to a pipe is equal to the resistance offered by a globe valve.

For example, suppose that a 3-inch pipe 128 feet long contains four elbows and three globe valves. Each globe valve has a resistance of $60 \times 3 = 180$ inches, or 15 feet, of straight 3-inch pipe. Each elbow has a resistance of $\frac{2}{3} \times 15 = 10$ feet of 3-inch pipe. The resistance at the entrance is that of 15 feet of 3-inch pipe. Then, the equivalent length of pipe with which to make calculations is $L = 128 + 15 + (4 \times 10) + (3 \times 15) = 228$ feet.

FLOW OF WATER IN PIPES

85. Finding Size of Pipe.—In power plants, piping is used to convey feedwater to boilers, cooling water to condensers, hot water to and from pumps, and so on. The determination of the size of pipe required to carry a known quantity of water, if it is to be made accurately, must take into account the length of the pipe, the number of bends, elbows, and valves, and the friction due to rubbing against the walls of the pipe at different velocities of flow. To consider the effect of these various factors, the calculations become intricate, and beyond the scope of this Section. However, it is possible to determine the approximate size of a pipe by simple general formulas. For example, if the quantity of water to be carried is stated in cubic feet per minute, the size of pipe may be found approximately by the formula

$$d = \sqrt{\frac{183\,Q}{v}} \qquad (1)$$

in which d = internal diameter of pipe, in inches;
Q = quantity of water, in cubic feet per minute;
v = average velocity of flow, in feet per minute.

If G denotes the number of gallons per minute, the formula becomes

$$d = \sqrt{\frac{24.4\,G}{v}} \qquad (2)$$

prevent the hot gases from striking the crown sheet and being cooled before combustion is completed. The temperature at which ignition of the volatile gases can take place is from about 900° to 1,200° F.; therefore, if unconsumed gases are brought in contact with plates having a temperature of from 350° to 400° F., they will be cooled below the ignition point, and if they are not subsequently brought to a temperature at which they will burn, they will pass out to the stack and the heat value of the fuel they contain will be wasted. This explains why a high furnace temperature, aided by incandescent walls of refractory brick, is valuable in promoting combustion and preventing fuel loss.

3. **Furnace Temperature.**—If the furnace is external to the boiler, and is bounded by firebrick walls, the furnace temperature may be as high as 2,500° or 3,000° F.; but if the furnace is internal, and surrounded by water-cooled plates, the temperature rarely rises above 2,000° F. A high temperature is desirable, for the reason already stated; and an additional reason is that the transfer of heat from the gases to the water is more rapid with a high than with a low furnace temperature. To insure complete combustion of the fuel gases, an excess of air above that theoretically required is always supplied to the furnace. At ordinary rates of combustion, the excess ranges from 25 to 50 per cent.; but when the fires are forced, the excess may be from 100 to 300 per cent. This air enters the furnace at a temperature of from 50° to 90° F. and escapes to the chimney at a temperature of from 400° to 600° F.; thus, air supplied beyond that needed for combustion reduces the furnace temperature and causes loss by carrying away heat.

4. **Effect of Composition of Coal on Furnace Volume.** Coal having a high percentage of volatile matter, such as bituminous coal, which burns with a long, smoky flame, requires a much larger combustion space than coal of low volatile content. Hence, the volume of the furnace is governed by the quantity and nature of the volatile matter in the fuel and the rate at which the fuel is burned. The Bureau of Mines has conducted experiments with bituminous coals of three grades

required does not vary in direct proportion to the quantity of volatile matter. For instance, doubling the rate at which the fuel is burned doubles the amount of volatile matter driven off from the coal in a given time; but it will be seen from the table that the combustion space is not doubled. For example, take Pittsburgh coal with a loss of 3 per cent. in undeveloped heat. At a rate of firing of 25 pounds of coal per square foot of grate, the furnace volume is 2.7 cubic feet per square foot of grate, whereas, at 50 pounds per square foot it is 3.7 cubic feet, or only about 37 per cent. larger; that is, doubling the rate of fuel consumption required an increase of only about 37 per cent. in furnace volume.

6. Firebrick Arches and Walls.—In locomotive boilers that burn bituminous coal, arches built over the fuel bed assist in promoting combustion. The arches are built of firebrick blocks and are supported by arch tubes. The firebricks become incandescent and thus tend to maintain a uniform temperature in the furnace. At the same time, the arch lengthens the travel of the hot gases and prevents cool air from striking the tube-sheet and firebox plates. The same principle may be adapted to other types of boilers. For example, the Scotch boiler or the Clyde boiler has furnace flues of large diameter opening into combustion chambers. The combustion chambers opposite the ends of the flues may profitably have firebrick linings; for, after the brick becomes heated, any unconsumed gases leaving the flue will be ignited by the incandescent brickwork and thus will be prevented from escaping to the stack unburned. Externally fired boilers have various arrangements of brickwork and baffles to prevent the escape of unconsumed furnace gases.

7. Distance Between Boiler and Grate.—If the setting of a water-tube boiler is such that the gases rising vertically from the fuel on the grates immediately come in contact with the tubes, they are chilled and the process of combustion is checked before they have become thoroughly mixed with air. To prevent this condition, it is advisable to set the boiler so that the tubes are well above the grates, thus providing a combus-

volatile matter, as Illinois coal; the diagonal B is for bituminous coal having from 18 to 35 per cent. of volatile matter, as Pittsburgh coals; and the diagonal C is for semi-anthracite and anthracite containing less than 18 per cent. of volatile matter, as Pocahontas and Georges Creek coals.

EXAMPLE.—A return-tubular boiler 72 inches in diameter is to be fired with bituminous coal containing 27 per cent. of volatile matter. Find (*a*) the distance from the grates to the shell and (*b*) the distance from the bridge wall to the shell.

SOLUTION.—(*a*) As the fuel contains 27 per cent. of volatile matter, the diagonal B, Fig. 1, must be used. At the bottom of the diagram locate 72 and proceed vertically to the line B. From this point proceed horizontally to the scale at the left, where 40 inches is indicated. This is then the height of the boiler shell above the grates. Ans.

(*b*) From the same point on the diagonal B proceed horizontally to the scale at the right, where 16 inches is indicated. This is the distance between the shell and the top of the bridge wall. Ans.

FURNACE AND ASH-PIT DETAILS

9. Furnace Mouth.—The fronts of boilers consist of steel or cast iron, lined with firebrick to prevent their warping and burning under the action of heat from the furnace. They contain the openings to the furnace and the ash-pit. The fire-door opening should be flared outwards on the side toward the furnace, as shown in the sectional view, Fig. 2, so that any part of the furnace may be reached easily by the firing tools.

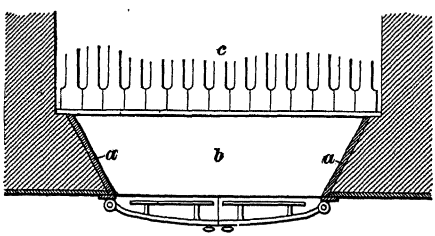


FIG. 2

The sides and front wall of the furnace are indicated by cross-section lines. The furnace mouth, or fire-door opening, is fitted with cast-iron cheek plates a at the sides, and a dead plate b forms the bottom of the opening and serves as a support for the front ends of the grate bars c; also, fresh fuel is thrown on the dead plate and allowed to remain until

renew the door linings, arches, side walls, and dead plates. One method of arranging water pipes for protection has been described. Another method of accomplishing the same purpose is shown in Fig. 6 (*a*) and (*b*). Two rings *a* of half-oval section, as shown at *b*, are connected by the pipes *c* and *d*. Connection is made with the water space of the boiler by the pipes *e* and *f*, so that the hollow rings are filled with water when

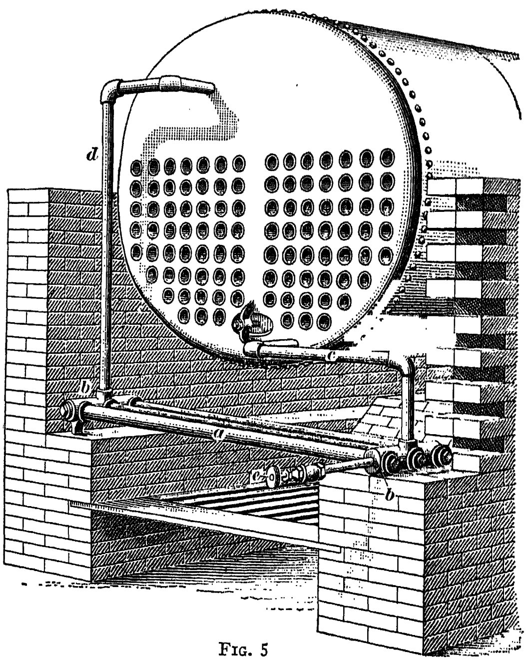


FIG. 5

the boiler is in operation. The rings are set in the boiler front and form the sides and arched tops of the fire-door openings. As the level *g h* of the top of the grates is above the bottom inside surface of the ring, a dead plate *i* is inserted. Blow-off connections *j* allow the rings and pipes to be cleaned of sediment.

12. Bridge Wall.—The bridge wall is a low wall built across from one side wall of the setting to the other, beneath

built to deflect the hot gases from the combustion space into the tubes. It must extend from one side wall to the other and must be so constructed that it will not break under repeated expansion and contraction. It may be either curved or flat. An example of flat arch is shown in Fig. 7. Angle-iron supports *a* extend from one side wall to the other and from them are hung a number of circular iron plates *b* by bolts *c*. The slab *b* that forms the arch is composed of refractory material that is prepared in plastic form and pressed into place over and around the plates *b* and bolts *c*, between the side walls and between the boiler and the rear wall *e*, after which it is allowed to dry and harden. By this construction, none of the metal in the supporting frame is exposed to the direct action of hot gases. The arch must be above the tubes, so that they are accessible at the rear for repairs; also, the joints between it and the

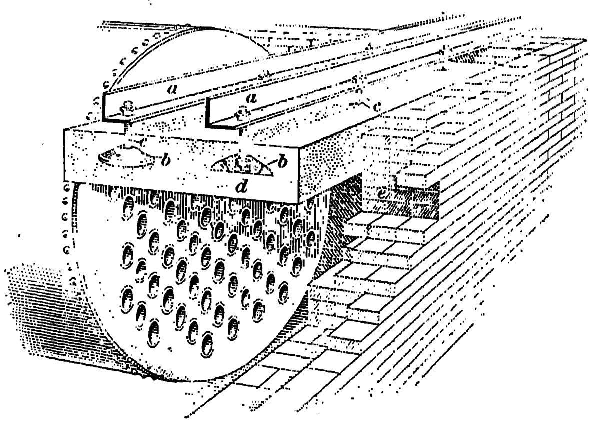


FIG. 7

walls must be tight, to prevent leakage of air into the setting, with consequent lowering of temperature of the hot gases. Asbestos rope may be used to plug up all crevices.

14. Ash-Pits.—The space below the grates of an externally fired boiler forms the ash-pit, which may be walled with brick or concrete. The size and shape of the ash-pit depend on the size of the boiler, the type of furnace and grates, and the

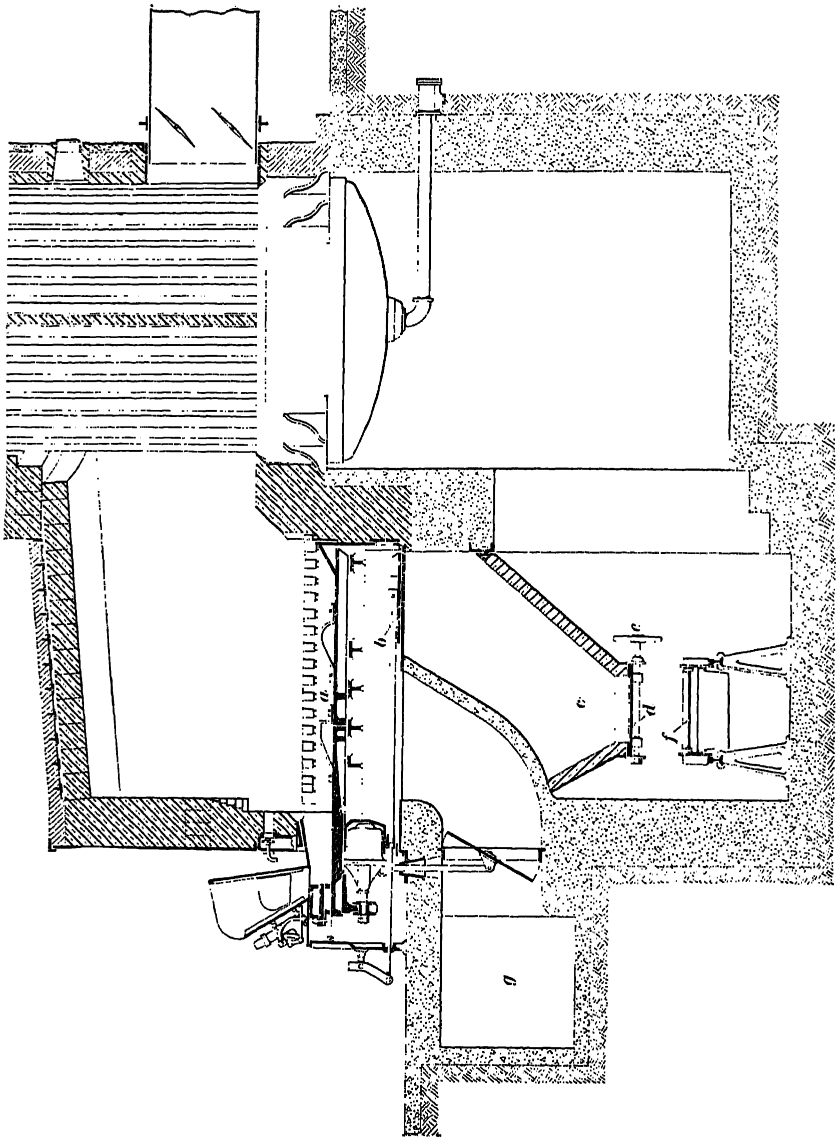


FIG. 9

a longer travel of the hot gases than is the case in the ordinary boiler setting. The firebrick walls surrounding the furnace maintain a more nearly uniform temperature and promote combustion of the gases.

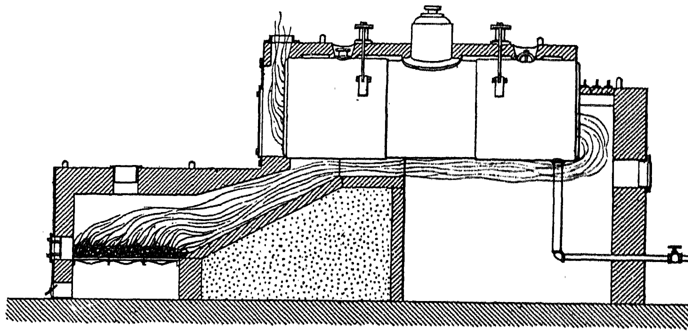


FIG. 10

17. Hawley Down-Draft Furnace.—The Hawley down-draft furnace, an example of which is illustrated in Fig. 11, is so called because the draft through one of the two sets of grates used is downwards instead of upwards. The upper

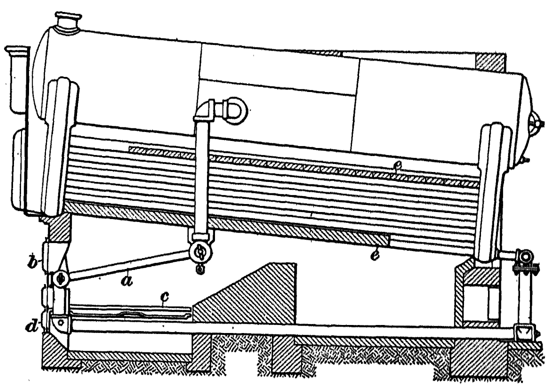


FIG. 11

grate *a* is a water grate; that is, it consists of pipes expanded into headers at their ends, the headers being connected to the water space of the boiler to insure continuous circulation of water. Fresh fuel is thrown on the grate *a* through the fire-

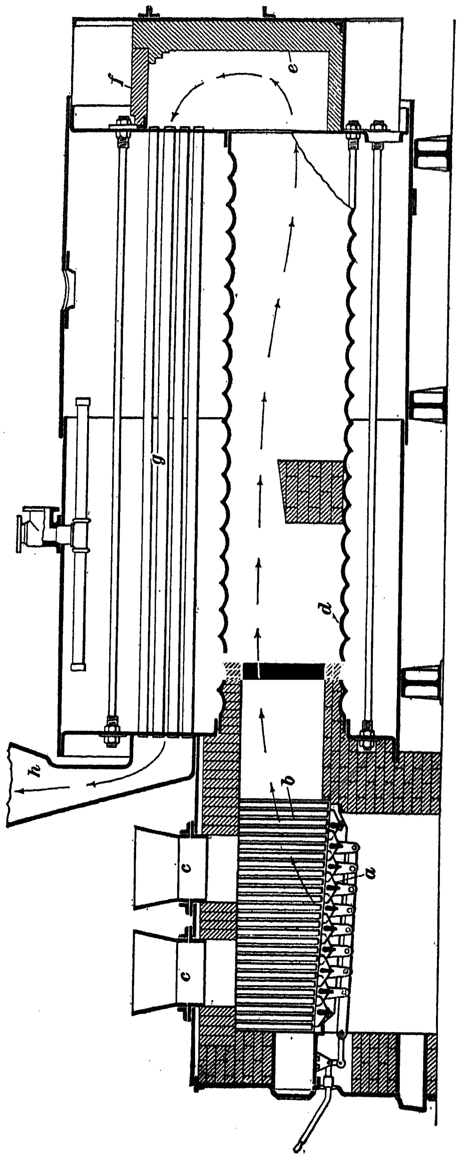


FIG. 13

being parallel with the arch *a*. Back of the arch *a* is built a brick pier *d* against which the gases strike and are deflected back upon themselves, thus insuring a more thorough mixing of the gases and air. The water-tubes *e* are baffled at *f* to give the gases a longer travel. By this form of furnace construction a high furnace temperature is obtained, owing to the intimate mixing of the gases and air and their combustion before they strike the cooler boiler surfaces.

21. Wooley Furnace.—The Wooley furnace and setting for a water-tube boiler are illustrated in Fig. 15. The furnace *a* is practically a Dutch oven and is so constructed as to

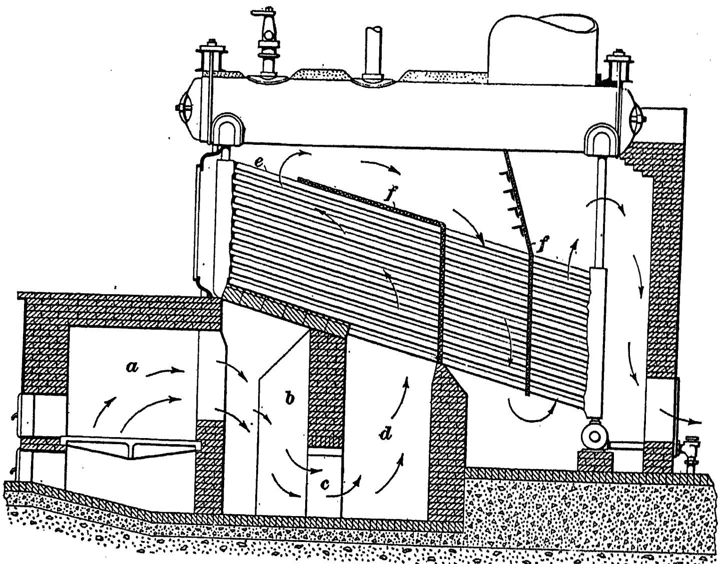


FIG. 15

provide a very large grate area and combustion chamber. A brick wall *b* is built up solid except at the bottom, where arched openings *c* are provided. A view of the wall is shown in Fig. 16, as it appears from the front of the furnace. Fire-bricks are used for facing the wall *b*, and as these bricks withstand and maintain high temperatures, the wall promotes combustion. By placing the gas openings *c* at the bottom of

section depends on the width of the grate, on the air space, and on the number of bar sections in each grate bar. It is the general practice to make the thickness across the lugs *b* twice the thickness of the bar *a*. The depth of the bar is made about 2 inches at the ends and ranges from 3 to 5 inches at the center.

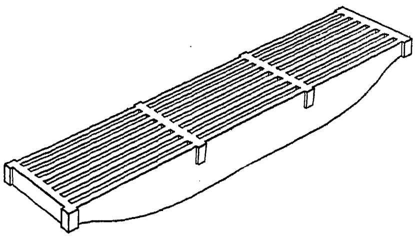


Fig. 18

For long furnaces the bars are made in sections 3 feet in length, and a bearer bar is placed in the center of the furnace to support the grate bars. Long grates are set with a downward slope toward the bridge wall of about $\frac{3}{4}$ inch per foot of length. This position facilitates the admission of air at the rear of the grate, and also the cleaning of the grate.

Grate bars are also made in sections having two or more bars united in a single casting, as shown in Fig. 18. Bars of this kind range in width from 3 to 6 inches and are stronger than the single-bar units. They have the disadvantage, however, that in case of breakage or warping, it costs more to replace them than to replace single bars. Another disadvantage is that the bars must be so thin, in proportion to their length, that they will warp out of shape, and consequently break, especially under forced firing.

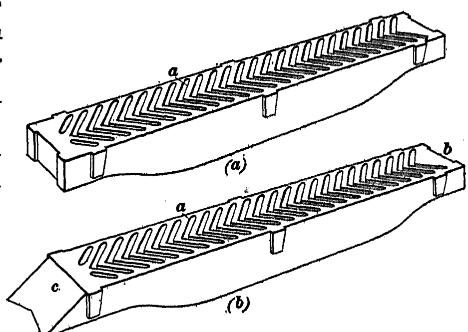


Fig. 19

24. The *herring-bone grate bar*, shown in Fig. 19 (*a*) and (*b*), can expand and contract freely, owing to the angular shape of the cross-bars *a*, and for this reason it is superseding the ordinary straight type. Herring-bone bars are made in various

space when caking coals are to be burned. Some varieties of bituminous coal will cake, that is, fuse together to a considerable degree, and the ashes and clinkers formed are of such size that a large part of them cannot pass through the air spaces unless these are large; the grate thus becomes clogged, shutting off the air from the fire, which reduces the rate of combustion and evaporation.

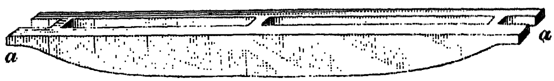


FIG. 22

28. Installing Stationary Grate Bars.—Grate bars must be installed in such a manner that they can expand freely and without damage to the boiler setting. The front ends of the grate bars are supported on the dead plate, and the rear ends are usually supported by the bridge wall. The space between the ends of the grate bars and their support will fill up with cinders and ashes, which will become hard and prevent the bars from expanding freely if this refuse is not removed frequently. To overcome this trouble, the grate bars may be supported by *bearer bars*, one form of which is shown in Fig. 22. The ends *a* of the bearer bars are set into the side walls of the furnace and the ends of the grate bars rest on the bearer bars; but a better construction is to set a cast-iron box *a*, Fig. 23, directly in the brick side walls and then place the bearer bars *b* so that the

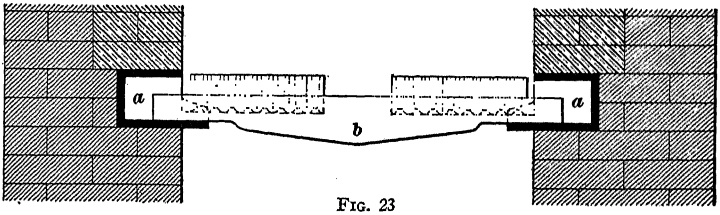


FIG. 23

ends rest on the bottom of the box *a*. This allows the grate bars and the bearer bars free expansion and contraction; also, the grate bars and bearer bars can be easily replaced when burnt out or broken.

and the segments *b* of the herring-bone pattern. The segments radiate from the round center *a*, and are supported by a ring that rests on lugs attached to the boiler shell.

SHAKING GRATES

31. Advantages of Shaking Grates.—With stationary grates, the fires are cleaned by tools inserted through the fire-door; consequently, during the cleaning period a large amount of cool air is admitted to the furnace, lowering its temperature and that of the gases, and causing contraction of the plates and setting. Shaking grates eliminate these troubles, because they are so constructed that the fires may be cleaned by moving levers outside the boiler setting. The grate bars of a shaking grate are hung on trunnions at the ends and rocked on the trunnions. The result is that the fuel bed is broken up, and the ashes beneath the live coal are shaken through into the ash-pit. Either anthractite or bituminous coal may be burned on shaking grates, and the cheaper grades may be used to better advantage on shaking grates than on fixed grates. The principle of construction of shaking grates of different makes is the same, but the details may differ.

32. Description of Grates.—One form of shaking grate is shown in Fig. 25. It consists of a number of transverse parallel bars having trunnions at the ends, by which they are supported and on which they may be swung. The lower arms of the grate bars are connected by the bars *a* and *b*. Ordinarily they stand as shown in the right-hand half of the illustration. When it is desired merely to shake the fire and thus remove the bottom layer of ashes, the points *c* are moved from the level shown to the lowest position the connections will permit. The points follow the back of the bar immediately in front of them; thus no unusual opening is made through which fine fuel may fall into the ash-pit. The end bar *d* is curved to fit the frame. When the ashes have accumulated to a considerable thickness, or when they have fused together in a mass of clinkers, the points *c* are thrown upwards, as shown in the left-hand half of

the illustration, thus forming a series of deep pockets that are closed at the bottom by the main rib, or back plate, of the grate bars. The act of throwing the points upwards breaks up the fused masses, which drop into the pockets and are discharged when the bars are returned to their normal position.

33. The grate bars in Fig. 25 are operated by means of a handle fitting the levers shown at *e*. By means of these levers, either half of the grate can be shaken independently, making it possible to clean one half of the fire at a time, without opening

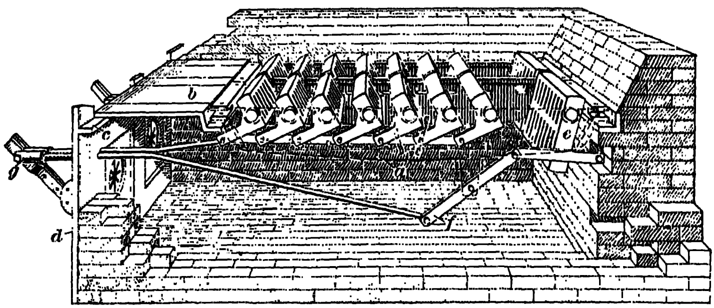


FIG. 26

the fire-door. The two levers can, however, be locked together and all the grate bars worked back and forth simultaneously. In Fig. 26 is shown another type in which the grate is divided into right and left halves, or sections. Either side can be shaken or dumped independently of the other. The trunnion bar or bearer bar *a* that supports the ends of the grates is shown merely by dotted lines so as to disclose the arrangement of the grate bars and how they are linked together. The plate *b* is the dead plate and it rests on the rib *c* of the boiler front *d* and supports the bearer bar *a*. A dump plate *e* is placed at the rear for removing clinkers that cannot be broken by shaking the grate bars. The dump plate is operated by a link *f* that can be rocked back and forth by the shaker lever at *g*.

erosion, and wear—points that must be considered in the case of brick for furnaces. A cubic foot of firebrick wall requires seventeen 9-inch straight bricks. If arch bricks, wedge bricks,

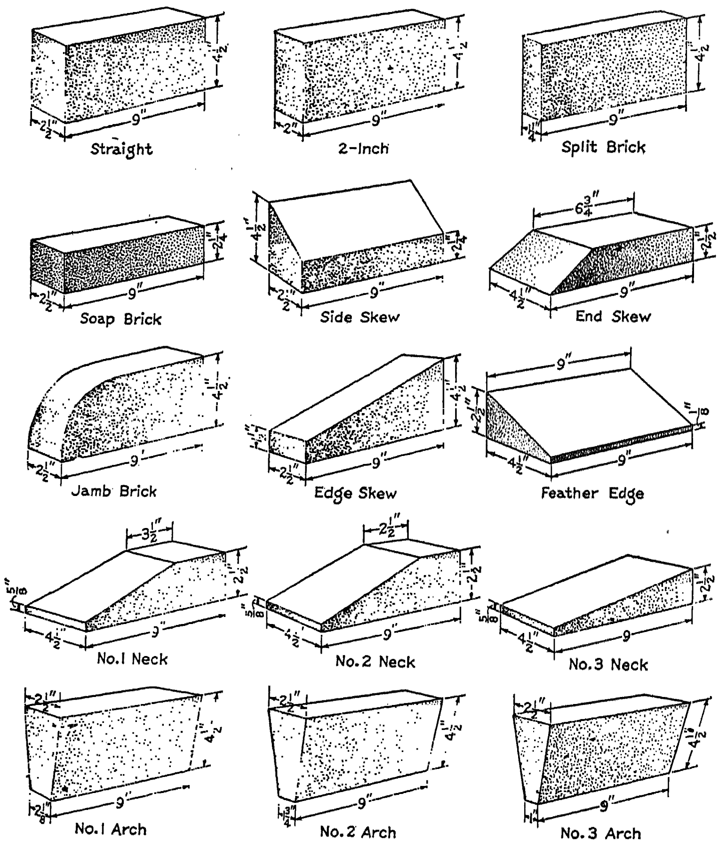
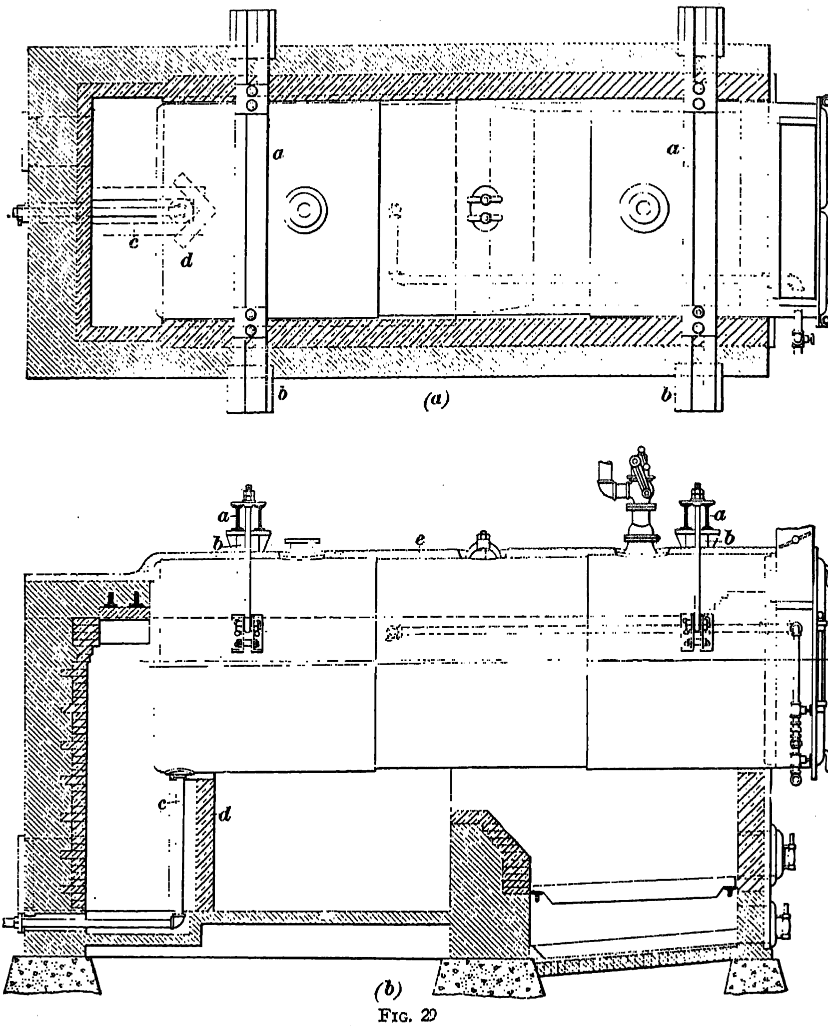


FIG. 27

or other special shapes are used, the quantity required may be taken as 10 per cent. more than for straight bricks. In laying common red brick, it is well to allow 9 cubic feet of sand and 3 bushels of lime for laying 1,000 bricks.

37. The type of wall shown in Fig. 28 (*b*) is solid throughout and is practically as expensive to build as the one just



(*a*)

(*b*)

FIG. 29

described. As the heat of the furnace affects the entire wall, cracks are more likely to develop in the solid wall than in the wall with an air space. The construction shown in (*c*)

In all four of the forms shown, it will be observed that the top of the wall is not built directly against the boiler shell; instead, a clearance of about 1 inch is left, and this space is filled with asbestos rope. If the brickwork were built against the boiler, the expansion and contraction of the shell would eventually cause cracks to develop in the setting. The asbestos rope forms a compressible joint and at the same time prevents inward leakage of air.

39. General Arrangement of Boiler.—The general arrangement of a return-tubular boiler and its setting is shown in Fig. 29; (*a*) is a plan view from above, the walls being shown in section at the level of the center line of the boiler; (*b*) is a partial longitudinal section taken in a vertical plane through the center line; and Fig. 30 is a combined end view and transverse section. The boiler is supended from the transverse girders *a*, which are supported by the cast-iron columns *b* outside the walls. The rear end of the boiler is $1\frac{1}{2}$ inches lower than the front end, so that sediment will naturally collect at the rear, where it may be removed through the blow-off pipe *c*. This pipe is protected from the direct action of the hot gases by a **V**-shaped brick pier *d* built in front of it. The horizontal part of the pipe, leading out through the rear wall, is contained in a trench in the floor and is covered with a steel plate or loose bricks. The part of the boiler shell not enclosed by brickwork is covered with a layer of non-conducting material *e* from 2 to 3 inches thick, over the surface of which is spread a thin coat of Portland cement. A clearance of 1 inch is left between the ends of the bridge wall and the side walls, to allow for expansion, as shown at *f*, and the space is filled with asbestos rope.

SUPPORTS FOR RETURN-TUBULAR BOILERS

40. Columns.—Either cast-iron or steel columns may be used to support the cross-beams from which the boiler is suspended. Four columns are required, and they are set outside the brickwork and rest on suitable footings. Three boilers 78 inches in diameter may be supported by one set of four

TABLE III

PROPORTIONS OF SQUARE CAST-IRON COLUMNS

Diameter of Boiler Inches	Length of Tubes Feet	Length of Column Ft.	Length of Column In.	1 Boiler Width	1 Boiler Thickness	2 Boilers Width	2 Boilers Thickness	3 Boilers Width	3 Boilers Thickness
54	16	10	6	6	$\frac{3}{4}$	6	$\frac{7}{8}$	6	1
60	16	11	0	6	$\frac{3}{4}$	6	$\frac{7}{8}$	6	1
60	18	11	0	6	$\frac{3}{4}$	6	$\frac{7}{8}$	6	1
66	16	12	0	7	$\frac{3}{4}$	7	$\frac{7}{8}$	7	1
66	18	12	0	7	$\frac{3}{4}$	7	$\frac{7}{8}$	7	1
72	16	13	0	8	$\frac{3}{4}$	8	$\frac{7}{8}$	8	1
72	18	13	0	8	$\frac{3}{4}$	8	$\frac{7}{8}$	8	1
72	20	13	0	8	$\frac{3}{4}$	8	$\frac{7}{8}$	8	1
78	16	13	6	8	$\frac{3}{4}$	8	$\frac{7}{8}$	8	1
78	18	13	6	8	$\frac{3}{4}$	8	$\frac{7}{8}$	8	1
78	20	13	6	8	$\frac{3}{4}$	8	$\frac{7}{8}$	8	1
84	18	14	0	8	1	8	1	8	$1\frac{1}{8}$
84	20	14	0	8	1	8	1	8	$1\frac{1}{8}$

Dimensions of Column, in Inches

TABLE IV

PROPORTIONS OF H-BEAM COLUMNS

Diameter of Boiler Inches	Length of Tubes Feet	Length of Column Ft.	Length of Column In.	1 Boiler Depth Inches	1 Boiler Weight Per Foot Pounds	2 Boilers Depth Inches	2 Boilers Weight Per Foot Pounds	3 Boilers Depth Inches	3 Boilers Weight Per Foot Pounds
54	16	10	6	5	18.7	5	18.7	6	23.8
60	16	11	0	5	18.7	6	23.8	8	34.0
60	18	11	0	5	18.7	6	23.8	8	34.0
66	16	12	0	5	18.7	8	34.0	8	34.0
66	18	12	0	5	18.7	8	34.0		
72	16	13	0	6	23.8	8	34.0		
72	18	13	0	6	23.8	8	34.0		
72	20	13	0	6	23.8	8	34.0		
78	16	13	6	6	23.8	8	34.0		
78	18	13	6	6	23.8	8	34.0		
78	20	13	6	8	34.0				
84	18	14	0	8	34.0				
84	20	14	0	8	34.0				

Proportions of Column

SETTINGS OF WATER-TUBE BOILERS

42. Methods of Supporting Boilers.—The construction of the side walls of the settings of water-tube boilers is similar to that of the walls for return-tubular boilers; but the methods of supporting water-tube boilers depends altogether on the type of boiler, size of installation, and local conditions. For example, the Babcock & Wilcox boiler is suspended from cross-beams that rest on columns, the suspending rods forming loops beneath the steam drum at the front and the rear. The Heine boiler is supported by the front and rear walls of the setting, the water legs at the front and the rear resting directly on plates set into the brickwork. The Edge Moor boiler may be suspended from overhead cross-beams or it may be supported by short columns riveted to the water legs at the front and the rear. Similar methods are used with the various other types of water-tube boilers.

43. Baffles.—To direct the flow of hot gases around and over the tubes of water-tube boilers, it is the practice to build baffles between or across the tubes. The gases are thus compelled to make a longer circuit inside the setting and give up a greater percentage of their heat. Baffles are commonly built of tiles made in suitable form and size to fit the particular type of boiler in which they are to be used.

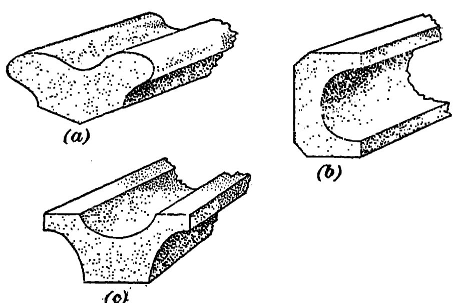


FIG. 32

Three forms of tiles are illustrated in Fig. 32 (*a*), (*b*), and (*c*), these being known as **B**, **L**, and **T** tiles, respectively. They are intended to be used, primarily, in boilers that have horizontal tubes, or tubes nearly horizontal. Another way of building baffles is to make them of a plastic refractory material that is put in place while wet. After it has dried and has become hardened by the heat, it forms a one-piece baffle.

day work; nor can they be obtained for long periods by hand firing when the boilers are operated at two or three times their normal capacity. Boiler firing is hard and, in many cases, far from pleasant work. Most boiler rooms are hot and many are poorly lighted and ventilated—conditions that make it difficult for any but the best of men to keep up their interest in their work.

47. With the best automatic stokers the fireman is relieved from much of the most severe and difficult part of his work; he is thus more free to devote suitable care and attention to the operation of the furnace. The coal is fed to the furnace at a uniform rate and in such a manner that the gases distilled from it are thoroughly mixed with a proper supply of air; the gases are then conducted through a part of the furnace in which there is a high enough temperature to insure their complete combustion. When the coal supply and air supply are properly adjusted to suit the working conditions, the continuous and uniform manner in which the fuel is fed to the furnace insures a high and practically uniform temperature, which is favorable for the complete combustion of the gases and relieves the boiler from the stresses produced by the sudden changes in temperature that occur when cold air enters the fire-door during hand firing.

48. Economic Considerations.—Automatic furnaces are more expensive, in both first cost and maintenance, than furnaces for hand firing, and in small plants they save little or nothing in the cost of labor; in these cases the question of economy in their use depends on the possibility of a saving in coal and of wear and tear on the boiler. In the matter of coal they have the advantage of successfully burning cheap grades of fuel that could not be used with ordinary methods of hand firing. Automatic furnaces will give better results in the matter of smoke prevention than can be obtained by hand firing, unless an unusual degree of care and attention is given to the management of the fires. In large plants, especially where some of the modern systems of coal- and ash-handling machinery are used, automatic furnaces effect a very considerable

relation between the length and width of the furnace. Each case must be considered as an individual problem. The customary method is to supply the stoker manufacturer with all the data as to type and size of boiler, kind of fuel, nature of service, maximum rate of steam generation, and so on, and let him provide a stoker to meet the conditions.

OVERFEED STOKERS

51. General Construction of Overfeed Stoker.—The overfeed stoker usually consists of an inclined grate made up of a series of bars, part or all of which may be movable. The fuel is fed on to the inclined grate at the upper end, after passing over a dead plate on which it is partly coked, or deprived of its volatile matter. The burning fuel then moves down the incline, burning as it descends, its movement being caused by the inclined position of the grate as well as by a slight rocking or tilting of some or all of the grate bars. By the time the fuel has reached the bottom of the incline, it is completely burned, and the ashes are dumped into a pit. The hopper from which fresh fuel is supplied to the stoker may be at the front or at the side of the furnace, and so the stoker may be of the front-feed type or of the side-feed type.

52. Roney Stoker.—The Roney stoker, shown in Fig. 33, is an overfeed stoker of the front-feed type. The coal is fed into the hopper *a*, at the bottom of which is an inclined pusher plate *b* to which a slow reciprocating movement is given by an eccentric mounted on the shaft *s*. At each inward movement of the pusher plate a quantity of fresh coal is pushed down and inwards upon the dead plate *c*, where it is subjected to the heat of the furnace and has most of its volatile matter driven off. The pressure of the fresh fuel fed from the hopper causes it to fall upon the stepped grate bars *d*, which run crosswise of the furnace and are supported by end trunnions. By the time the coal has reached the lower end of the inclined grate, all combustible matter has been burned and only ashes and clinkers remain, these collecting on the dump plate *e*. The dump plate

is hinged at its rear edge, next to the bridge wall, and may be dropped by moving a hand lever that extends to the boiler front. The ashes are thus dumped into the ash-pit. To prevent fuel from sliding off the grate and going into the ash-pit when the dump plate is lowered, a curved guard *f*, also hinged at the bridge wall, is raised to the upper dotted position by moving the handle shown, and is lowered after the dump plate has been brought back into normal position.

53. As combustible gases are driven off during the coking of the fuel on the dead plate *c*, Fig. 33, air for their combustion may be admitted through hollow tile *g*. To maintain a high temperature in the furnace and promote efficient combustion, a firebrick arch, part of which is shown at *h*, may be built above the grate. The lower end of each grate bar *d* fits into a rocker bar *i* to which a reciprocating motion is given by the same eccentric that drives the pusher plate. The bars *d* are thus rocked on their end trunnions, and this rocking assists in causing the fuel to move down the grate. This stoker is designed especially for burning all grades of bituminous coal, but it may be used successfully for burning fine anthracite. It operates with natural draft and the rate of combustion of coal varies from 35 pounds per square foot of grate area per hour in the case of coking fuels to 50 pounds per hour in the case of free-burning fuels.

54. Wilkinson Stoker.—The Wilkinson stoker is a front-feed stoker designed more particularly for the burning of fine anthracite. In Fig. 34 it is shown applied to a horizontal return-tubular boiler, while in Fig. 35 is shown an enlarged view of the grate itself. Like parts have been lettered the same in both illustrations. The grate bars *b* are cast hollow, with nearly horizontal openings leading from the interior through the risers of the steps that form the upper surface; these openings are shown in the black sectional portion of the left end of the bar. To each grate bar is given a to-and-fro motion in a horizontal direction by the rock shaft *f* and links *g*, Fig. 34, the ends of the bars being supported by, and sliding on, the hollow cast-iron bearing bars *d*. A pusher *i*, Fig. 35,

fastened to the upper end of each grate bar, pushes the coal from the hopper *a* through the opening in the furnace front onto the bars.

55. The motion of the grate bars, Fig. 35, gradually forces the coal downwards and deposits the ashes and clinkers on the clinker grates *e*, from which they are finally pushed into the ash-pit. Practically all the air for the combustion of the coal is drawn into the upper ends of the hollow grate bars by the steam jets *c*, and forced into the fire from the openings in the

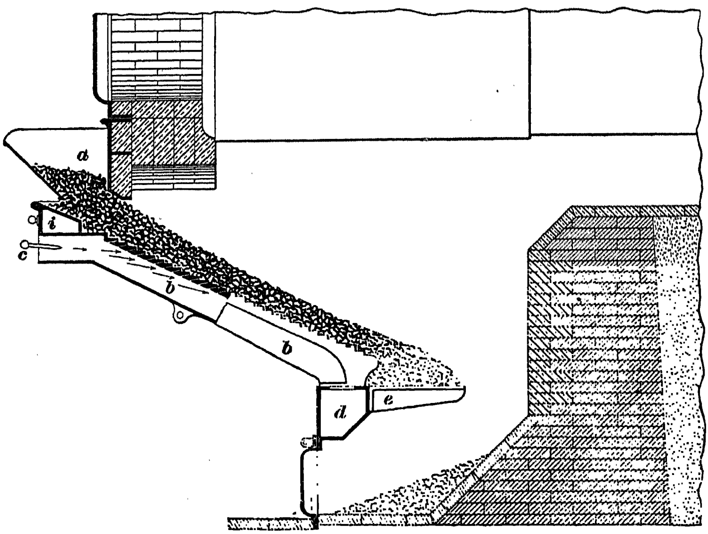


FIG. 35

tops of the bars. In this case, the steam jets, in addition to furnishing draft, serve an important purpose in keeping the bars moderately cool, thus preventing both their destruction by the heat and the sticking of the clinker, which with anthracite often causes considerable trouble if no special provision is made to overcome it. The advantages derived from this use of the steam jet are considered of sufficient importance to more than balance any possible loss of heat, and it is recommended by the makers that the steam be used, even where sufficient chimney draft is available to burn the fuel.

plate *f* and burn. After the coked fuel has been pushed from the plate *b*, it travels slowly down the sloping grates *h*, and during this movement of the fuel bed, air is supplied through the grates.

57. The grate bars are arranged alternately in pairs, each pair consisting of a stationary bar and a movable bar. The stationary bar, Fig. 37 (*a*), is ribbed on both sides with projections *a* that break up the air supply into many small jets and also prevent the fine coal from dropping through into the ash-pit unburned. Near the bottom of the bar the ribs *a* are omitted, as at this point the fuel has gone through the coking stage, and a more liberal amount of air is needed. The stationary bars, as shown in Fig. 36, rest against the air box *c* at the top, and at the lower end are supported by the bearer rod *i*. The movable grate bar, Fig. 37 (*b*), is a plain bar having a circular opening *a* that fits over the pivot *b* of the stationary bar in (*a*). Movement is given to the movable bars, as shown in Fig. 36, by the rocker-shafts *j*, which have cams *k* that engage with the lower ends of the movable bars. As the rocker-shafts oscillate, the cams force the lower ends of the movable bars up and down. This action breaks up the fuel bed sufficiently to promote combustion and causes the fuel to move down on the grate.

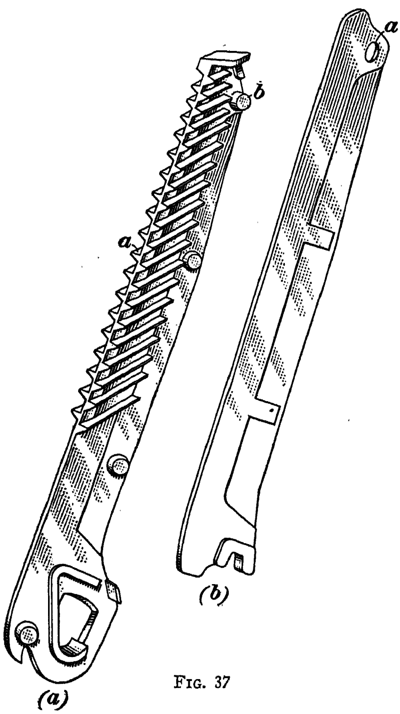


FIG. 37

58. At the bottom of the grates, Fig. 36, is a clinker breaker *l* that is oscillated by a link mechanism outside. The

59. The movable parts of the stoker are driven by an external mechanism arranged on the front of the furnace, as shown in Fig. 38. A bar *a* extends across the front and is supported by brackets. It is connected by a rod *b* to a pin on the worm-gear *c*, which is rotated by gearing driven by a motor or a small steam engine; thus, as the gear *c* rotates, there is given to the bar *a* a reciprocating movement in its supporting brackets. Links and levers *d* connect the bar *a* to shafts *e*, which are the shafts of the sectors *e* shown in Fig. 36. The reciprocating movement of the bar *a*, Fig. 38, thus causes the shafts *e* to oscillate and moves the pusher blocks *d*, Fig. 36, thereby feeding the coal to the grates. The bar *a*, Fig. 38, is also connected by levers *f* to the shafts *g*, which correspond to the shafts *j*, Fig. 36, that carry the cams which give movement to the movable grate bars. Thus the reciprocating motion of the bar *a*, Fig. 38, oscillates the shafts *j*, Fig. 36, and rocks the alternate bars of the grates. A link *h*, Fig. 38, connects the bar *a* to the clinker-breaker shaft *i*, shown at *l*, Fig. 36; thus, the shaft *l* is oscillated, resulting in the breaking up of the clinkers. The amount of swing, or oscillation, of the shaft *l* is adjustable, so that the movement may be made to suit the percentage of ash in the fuel. This type of furnace may be set directly beneath the boiler, but it is usually placed outside the main setting, like the Dutch oven.

UNDERFEED STOKERS

60. Characteristics of Underfeed Stokers.—Underfeed stokers are arranged at the front end of the boiler, with the grates in either a horizontal or an inclined position. The coal is fed from hoppers and is forced into the furnace by rotating screws or by the intermittent movement of reciprocating plungers. The principle of operation of the underfeed stoker is that fresh coal is fed from beneath the fuel bed. The volatile gases are given off as the coal passes up through the fire and are subsequently ignited in their passage. Such a system, if properly managed, brings the fuel gases and air into direct contact in the incandescent zone of the fuel bed

that moves forwards and backwards in a cylinder under steam pressure. The form of the retort *b* and the pusher blocks *d* is shown in Fig. 40. Along the top of the retort are hollow blocks *f* that have openings called tuyères, which permit the air to flow into the coking fuel bed. The blocks *f* are the only parts of the retort that come in contact with the fire. The cross-sectional view, Fig. 39 (*b*), shows the position of the blocks *f* and the dead plates *g* in the furnace. The air introduced under the dead plate and through the hollow blocks keeps these parts from burning out for a long period. The forward and backward movement of the ram *c* and the pusher blocks *d* forces the fresh coal to move upwards in the retort and breaks

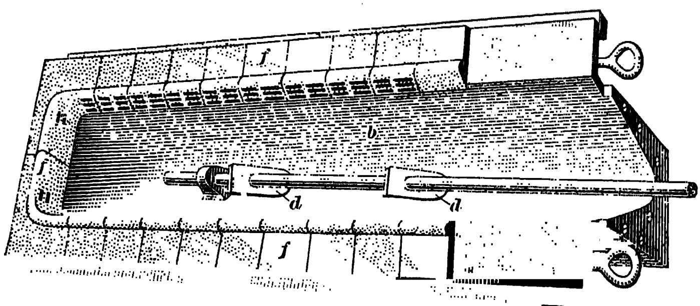


FIG. 40

up the fire, automatically slicing the fuel bed at the same time. Air is introduced under the stoker through a duct *h*, which can be opened or closed to the air blast by a blast gate controlled from the front of the furnace. The illustration shows only one unit under a boiler; but in large installations several units are arranged side by side, as in Fig. 41, the reference letters of which correspond with those of Fig. 39 in the case of corresponding parts.

62. Cleaning Jones Stoker.—As the movement of the ram continually forces the fuel back into the furnace, the ash and clinker are eventually deposited on a balanced dump plate *i*, Fig. 41. By tilting the dump plate, the ash and clinker fall to the ash-pit below, which in large installations is specially constructed with an ash-removal system. In the example

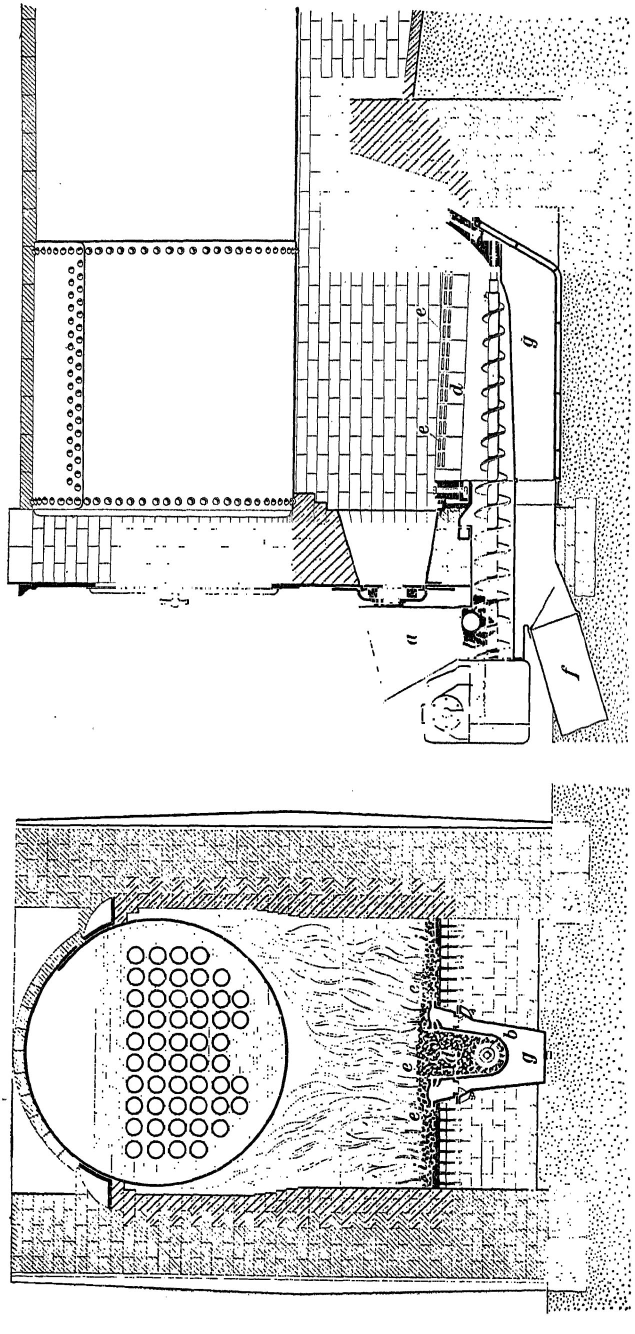


Fig. 42

front and the rear of the furnace and the top travels from front to rear. The coal is fed on to the moving grate at the front and burns as it is carried toward the rear of the furnace, the ashes being dumped at the rear, where the grate turns down around the rear drum. This type of grate is extensively used in burning soft coal containing a large percentage of volatile matter; but it is also adapted to burn coal of the poorest grade, such as anthracite culm. Over the front of the grate is built a firebrick arch, which, when the furnace is in operation, reflects heat on the fresh fuel fed at the front and causes it to

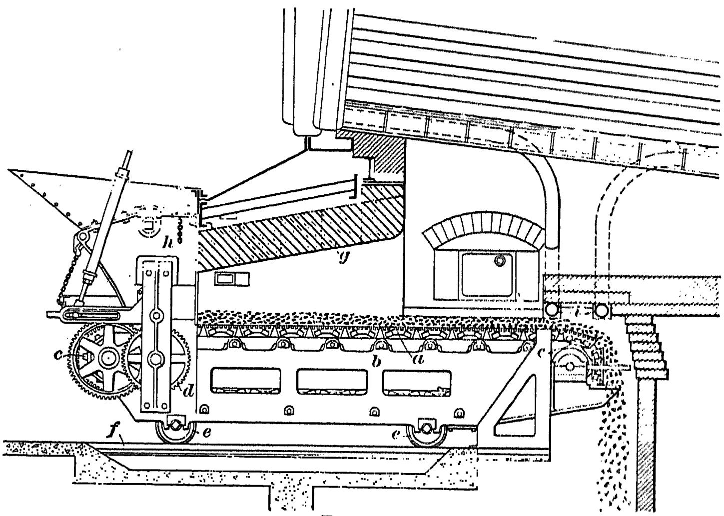


FIG. 43

ignite. The arrangement thus becomes practically a modification of the Dutch oven. The speed at which the grate travels can be altered to suit the rate of combustion demanded by the load on the boiler.

66. Green Chain-Grate Stoker.—The stoker shown in Fig. 43 is designed for burning non-coking coal with natural draft, and is known as type K. Another form, known as type L, has an inclined apron below the fuel gate at the front, on which the fuel is fed before it reaches the grate. This type is intended for coking coal, and the volatile matter is driven off

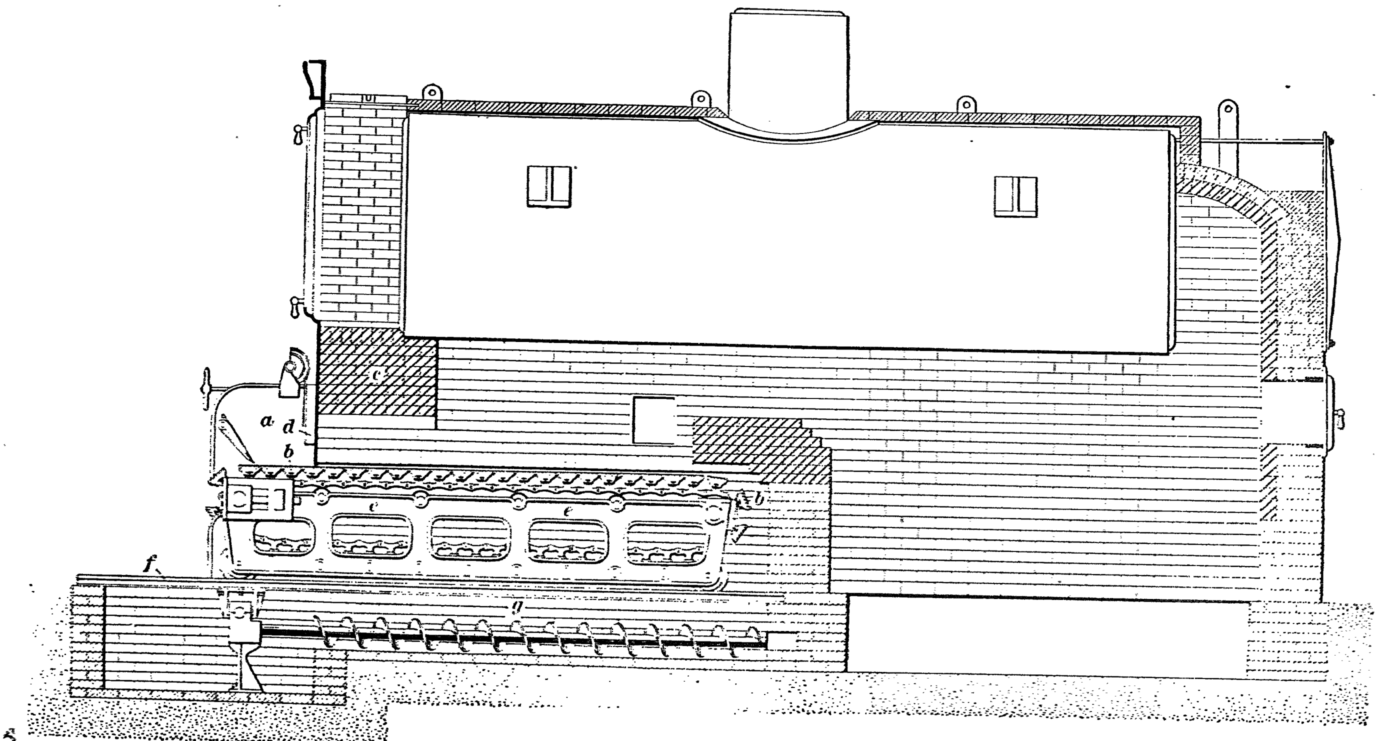


FIG. 44

STOKERS FOR SMALL POWER PLANTS

70. Coal-Throwing Devices.—Stoker installations for small power plants are practically prohibited on account of the cost and lack of space needed for setting the stoker. There are devices that not only give good results in firing coal, but increase the capacity and efficiency of hand-fired furnaces and reduce the labor involved. One such form is the coal-throwing device known as the Dayton fuel feeder, shown in Fig. 46. It is

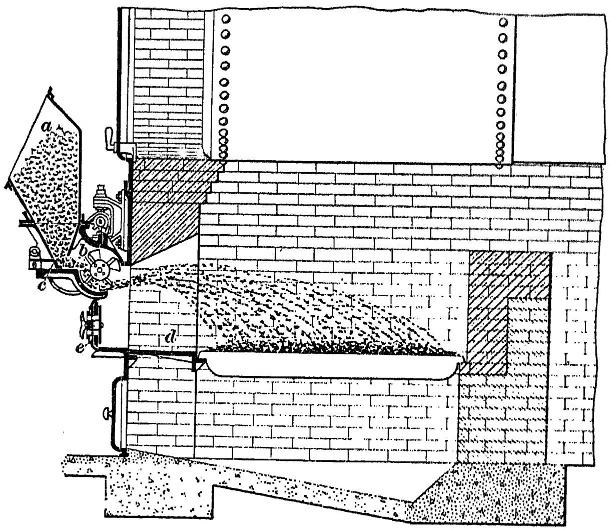


Fig. 46

arranged at the front of the boiler and, as in the larger types of stokers, a hopper feed is used. Coal is fed from the hopper *a* to a rotating wheel *b*, which delivers the coal in small amounts continuously to all parts of the grate. A pusher *c* is used to feed the coal to the wheel *b*. Whenever coal falls on the dead plate *d* it cokes and is subsequently pushed back on the grate by hand, the firing tools being inserted through the door *e*, which is also used when cleaning the fuel bed. The mechanism for driving the wheel *b* and feeding the fuel is operated by motor or steam engine and is so designed that the feed can be regulated to the required rate of combustion.

71. Coal fuel feeders of the type shown in Fig. 46 handle the lowest grades of power-plant coal, which are fired to maintain a thin fuel bed. The fuel is usually fired in a moist condition, but wet coal can be fired; in such a case the fuel must be watched to see that it does not hang in the hopper. Continuous light feeding of the coal and care in keeping the fire-doors shut reduce the liability of formation of smoke and insure good conditions for combustion. In case the proper size of fuel is not available, the fuel can be fired by hand upon the dead plate *d*, and after coking it may be pushed back onto the grate.

72. Hand-Fired Stokers.—Special forms of hand-fired stokers and grates are used in small steam-power plants. A typical form of such a grate and its general features of operation are shown in Fig. 47. The grate consists of a number of grate bars *a* trunnioned at their ends and arranged to be rocked by moving the rods *b*, which are attached to levers at the front of the boiler. The grate bars are arranged in two sections that may be rocked independently, thus enabling the coal to feed toward the dump plate *c* while it is being burned. The normal condition of the fuel bed is shown in (*a*) and the first cleaning operation is shown in (*b*), in which the dump plate *c* is lowered for the removal of ash and clinker. In (*c*) the grate section *d* is operated after the dump plate *c* is closed. The grate sections *a* are raised and thrown toward the rear, thus pushing the coked coal back onto the dump plate *c*. The second stoking operation is shown in (*d*), in which the grate section *e* is operated, advancing the coked fuel onto the grate section *d*. Green coal is then thrown on the grate section *e* at the forward end of the grate, as shown at *f*. A mechanical feed from a hopper can be installed in conjunction with the hand-operated stoker. This arrangement saves considerable labor in firing the fuel and prevents excess air from entering the furnace through the open fire-doors, as occurs in hand firing. Approximately 10 pounds of fuel can be burned per square foot of grate per hour for each .1 inch of draft in the furnace. Combustion rates up to 60 pounds have been obtained, but from 30 to 40 pounds of fuel per square foot of grate per hour is general practice.

2. Furnace Requirements for Oil Burning.—A furnace in which oil fuel is to be burned must be designed with the following requirements in mind:

2. The furnace must be of sufficient volume to insure thorough mixing of the oil spray and the air, with proper combustion, before the resulting hot gases are permitted to strike the boiler shell or tubes. A volume of 2 cubic feet per boiler horsepower has been found to give good results.

3. The burner, or atomizing device, must be so located that the oil spray will not strike the furnace walls or the boiler surfaces; for, if it does, there is a probability that oil will drip from those surfaces when the burner is put into operation, and enough oil may collect at the bottom of the furnace to cause an explosion when the furnace walls become heated. The flame of the burning oil spray should not be localized, but should be distributed so as not to produce local stresses in or blisters on any part of the boiler.

3. Furnaces for Oil Burning.—A form of setting for burning oil fuel under a water-tube boiler of the Heine type is shown in Fig. 1 (*a*) and (*b*). It will be observed that no bridge wall or combustion arch is used; as a result, a furnace of large volume is obtained. The side walls and floor of the furnace are lined with high-grade firebrick, to withstand the high temperatures produced by oil burning. This lining, when heated to incandescence, assists in maintaining and promoting combustion. The bricks *a* in the floor just in front of the burners are laid on supports *b* made of piping and are arranged so as to leave generous spaces *c* between them, through which air enters the furnace. The quantity of air supplied is regulated by a damper in the uptake and by doors at the front of the furnace. Baffles *d* of refractory tile are provided to lengthen the gas travel over the tubes. The burners *e* are set in openings *f* in the front wall of the furnace, and the oil is sprayed toward the rear of the boiler by either steam or air. This arrangement gives the burner the name of *front-shot burner.*

A Stirling boiler arranged for oil burning is shown in Fig. 2 (*a*) and (*b*). The sectional view (*a*) is taken transversely

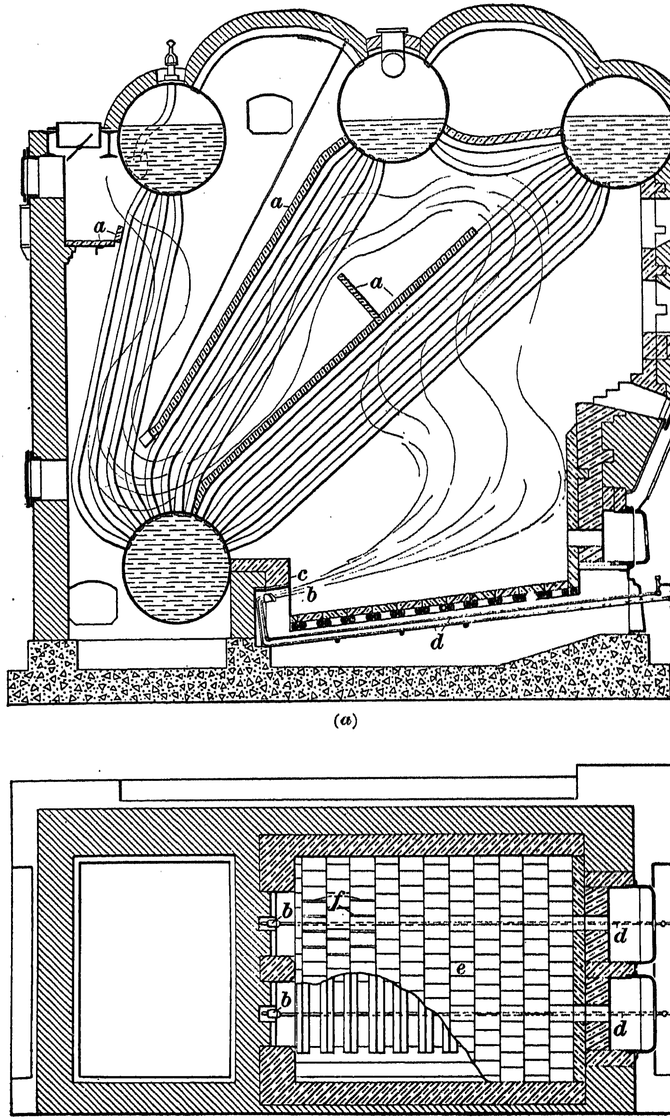


Fig. 2

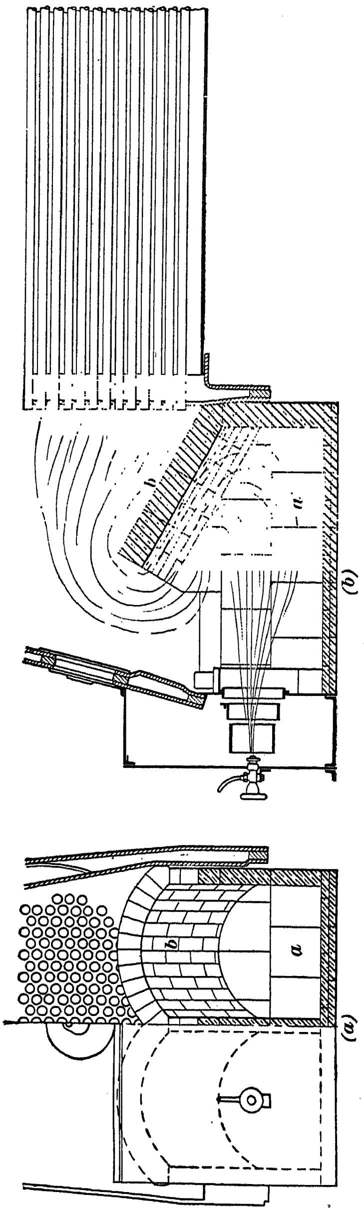


Fig. 4

through the drums of the boiler to indicate the position of the baffles *a* and the oil burners *b*. The burners, which are termed *rear-shot burners*, are placed at the back of the furnace, and as the firing is from the rear to the front, the gases travel forwards and then back under the front baffle *a*. When the burner is so placed it must be protected from the furnace heat. For this purpose a housing *c* of brick is set around it. The piping *d* to the burner is placed under the furnace floor *e*. The air is admitted into the furnace through openings in the floor *e*, and air slots *f* are allowed between the bricks in front of the burners *b* to prevent the formation of soot, which would form on the floor and fuse with the brick.

4. Oil Furnace for Scotch Boiler.—For burning oil in an internally fired boiler of the Scotch type, as in Fig. 3, the burners *a* are placed at the front of the corrugated furnaces. To protect the mouth of the furnace against the intense heat, a firebrick lining is built around the burner setting and back into the furnace to a distance of about one-half

nace volume with some types of firebox boilers, it is necessary to set the firebrick walls and floor well below the crown sheet. Doing this may necessitate building part of the brickwork outside the firebox, as shown in the illustration. The furnace illustrated is arranged for two burners, each of which has its own combustion arch.

Another form of arrangement is shown in Fig. 5. The lower part of the firebox is lined with firebrick *a*, and the arch bricks *b*

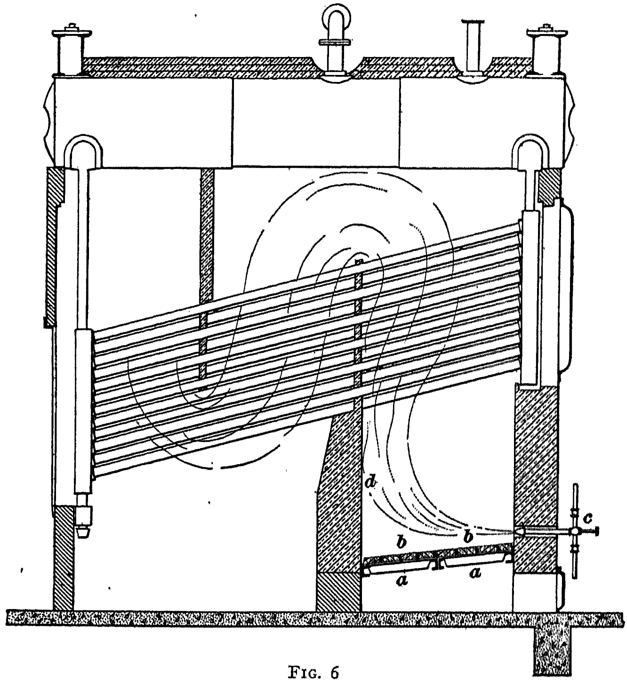


FIG. 6

are supported by the arch tubes *c*. The burner is located at *d*, so that the flames are directed against the target wall *e*. Air is admitted through the holes *f*, as well as through the hopper door *g* when it is opened.

6. Adapting Coal-Burning Furnaces for Oil Burning.—A boiler setting intended for the use of coal as fuel may be adapted to oil burning with little change, and in case of necessity

the coal is picked up, carried part way round, and dropped off the shelves, while at the same time it is acted on by the current of hot gases passing through the dryer and the heat transmitted

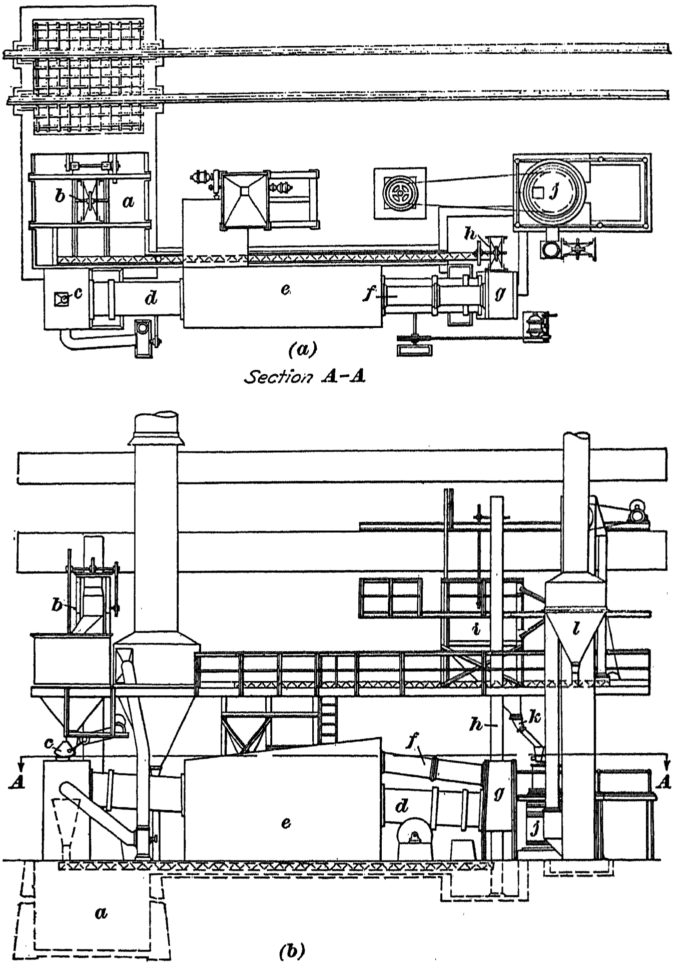


FIG. 7

through the shell of the dryer. As the dryer is inclined, the coal gradually works down to the lower end, where it is picked up by an elevator *h* and carried into a storage bin *i*.

Additional air for combustion enters through the adjustable register *i*, the damper-controlled ducts *j*, and the shutters in the ash-pit doors *k*.

10. Furnace Design for Burning Powdered Coal.—The furnace for burning powdered coal must be of such proportions that the fuel will be burned before the resulting hot gases touch

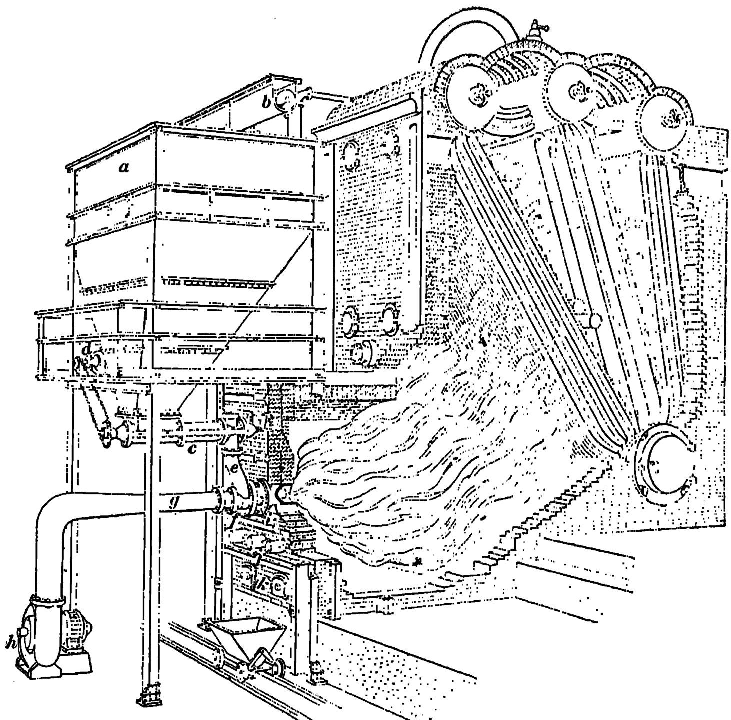


FIG. 8

the boiler surfaces. For bituminous coals high in volatile matter, the volume of the furnace may be satisfactorily taken as 2 to 2½ cubic feet for each boiler horsepower. The interior of the furnace should be made in the form of a cube, if possible, with the side walls sloping inwards toward the ash-pit, so that the dust and slag will slide easily into it. Furnaces are sometimes extended in the form of a Dutch oven to provide addi-

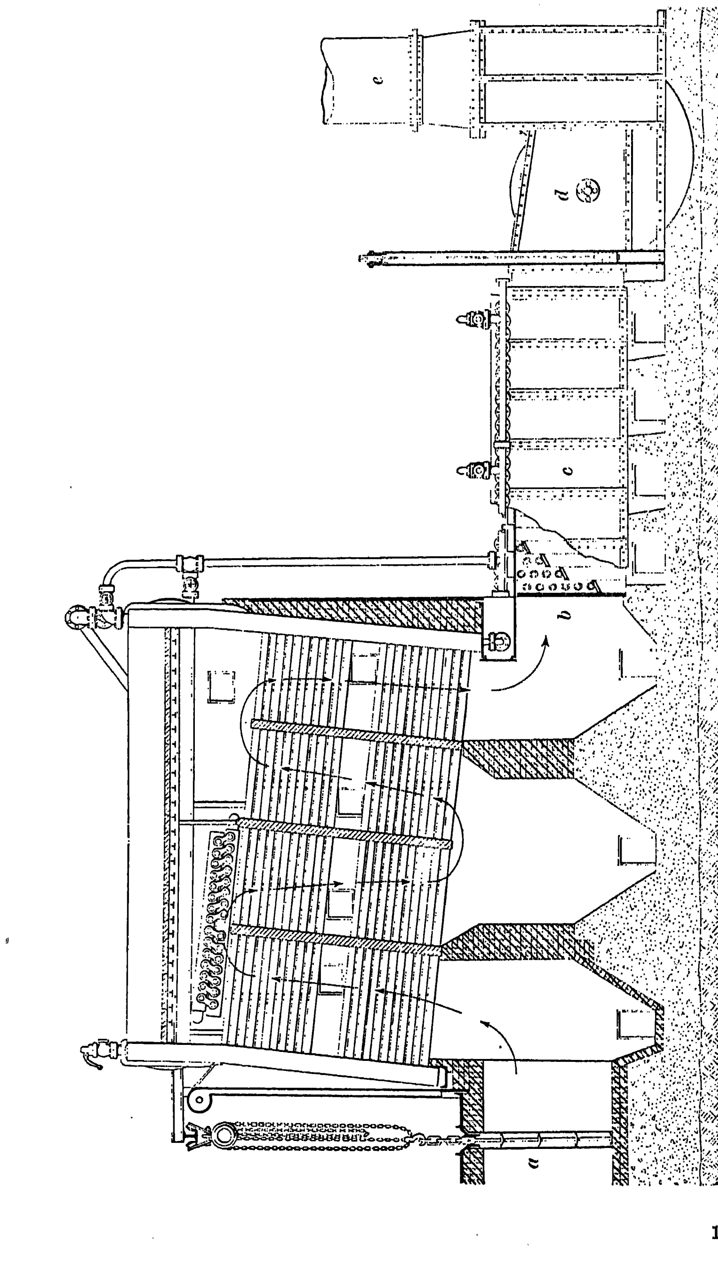


Fig. 9

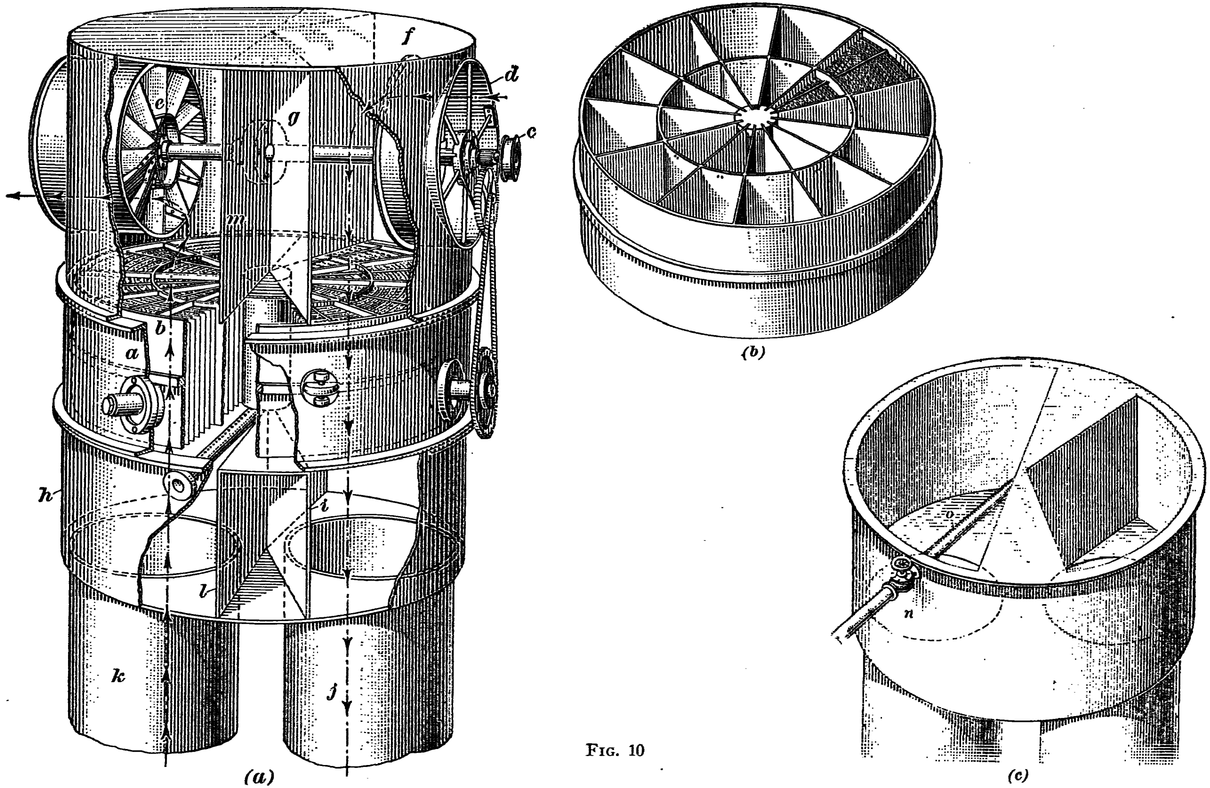


FIG. 10

two branches *d* and *e*, it is customary to provide a separating plate, or baffle, at the throat where the two branches unite.

16. In case a breeching must serve a battery of boilers, it is made tapering in form, so that its cross-sectional area

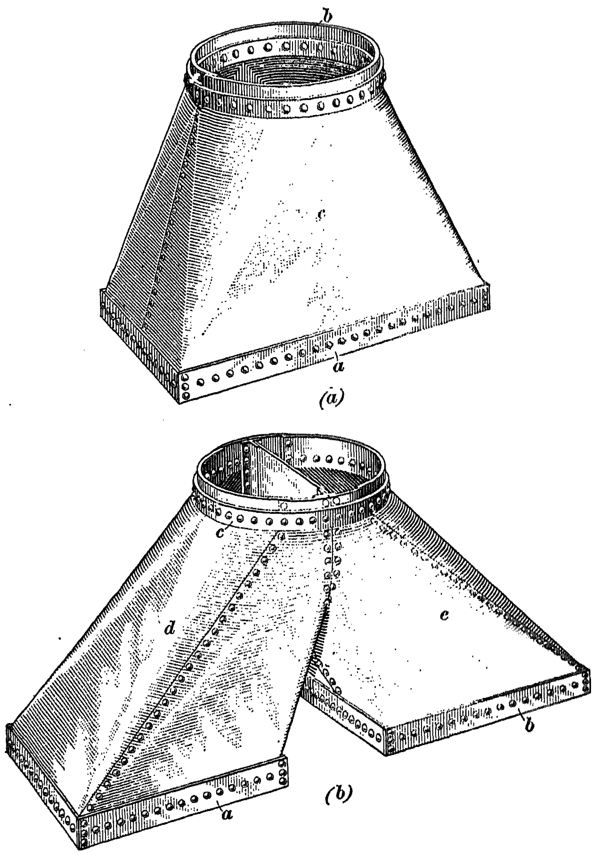


Fig. 11

increases toward the stack and thus accommodates the greater quantity of gases. Such a breeching is shown in Fig. 12. The sides are straight, flat surfaces and the top is arched. The bottom is flat, and in it are the openings *a* through which the gases from the boilers enter the breeching.

cross-sectional area of the breeching should be made larger than that of the stack. In general practice the cross-sectional area is made from 10 to 25 per cent. larger than the cross-sec

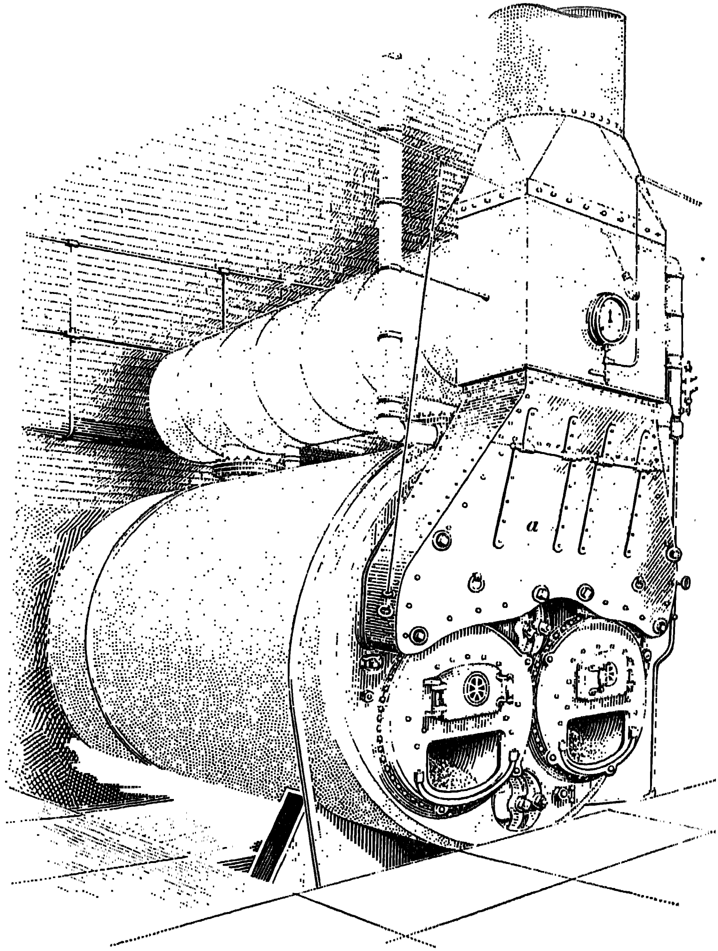


FIG. 13

tional area of the stack, depending on the nature of the fuel to be burned and the amount of flue dust expected. Builders of chimneys prefer to make the area of the flue opening from 7 to 10 per cent. larger than the cross-sectional area of the stack.

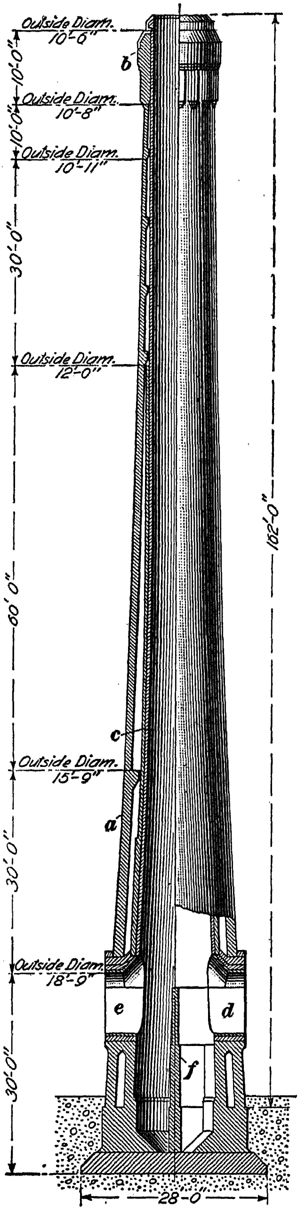


FIG. 15

iron plate to prevent the destruction of the bricks by the weather; some ornamental finish is usually added at the top of the chimney.

21. Iron or steel stacks are made of plates varying from $\frac{1}{8}$ to $\frac{1}{2}$ inch thick. The larger stacks are made in sections, the plates being about $\frac{1}{4}$ inch thick at the top and increasing to $\frac{1}{2}$ inch at the bottom; they are lined with firebrick about 18 inches thick at the bottom and 4 inches at the top. Some designers prefer to use no lining on account of the likelihood of corrosion and the difficulty of inspection, and also because the inside of lined stacks cannot be painted.

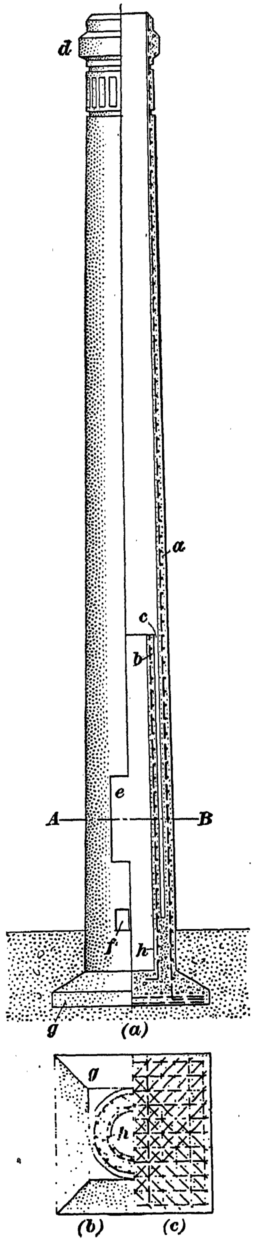
On account of the great concentration of weight, the foundation for a chimney should be carefully designed. Good natural earth will support from 2,000 to 4,000 pounds per square foot. The footing beneath the chimney should be made of large area. In compressible soils, piles should support the footing.

22. Brick Chimney.—A brick chimney 162 feet high is shown in Fig. 15. The flue is 12 feet 3 inches in diameter at the base, tapers to 8 feet half way up, and remains of the same size to the top. The outer wall *a* is $17\frac{1}{2}$ inches thick for the first 50 feet, 13 inches for 60 feet, and 9 inches thick to the ornamental top *b*. The core *c* is $13\frac{1}{2}$ inches thick for 20

for the gases to be somewhat cooled before coming in contact with the outer shell. Between the shells is an air space *c* that prevents the heat from penetrating to the outer shell. Since concrete expands under heat this space also permits the inner shell to expand as required.

25. At the top of the chimney, Fig. 16, is an ornamental cap *d* consisting of a heavy ring of concrete with extra reinforcement to stiffen the concrete at the top. Some distance above the ground is the flue opening *e* through which the gases are admitted to the chimney. The concrete immediately surrounding the flue opening is reinforced with extra steel rods and thickened by the omission of the air space at this place, as plainly shown in (*d*). Below ground is the footing *g*, consisting of a tapered block of reinforced concrete constructed as shown in (*b*) and reinforced as indicated in (*c*). The wall of the chimney is solid below grades, as shown at *h* in views (*a*) and (*b*).

26. The Wiederholdt chimney, Fig. 17, differs from the Weber chimney in being built without molds, the wall consisting of **H**-shaped tiles of the shape shown in Fig. 18. These tiles are laid up first to form a hollow wall into which



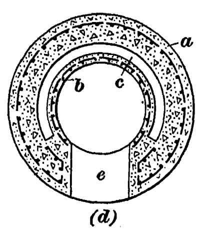


Fig. 16

27. Steel Chimney.—A self-supporting steel chimney is shown in Fig. 19. It is 225 feet high above the foundation, and the inside diameter of the shell is 14 feet 8 inches at the top and 17 feet at the top of the flare at the base, and the inside diameter of the lining is 13 feet 9 inches. It is set on a foundation about 16 feet high, built of dimension stone laid in Portland-cement mortar. (*Dimension,* or *cut, stones* are stones that have been cut to dimensions in advance of laying.) The chimney is composed of a number of rings made of plates 4 feet high by about 6 feet long and $\frac{1}{4}$ inch thick for the first 40 feet from the top, increasing in thickness by $\frac{1}{32}$ inch per 40 feet for 160 feet. The first 25 feet at the bottom is made of $\frac{7}{16}$-inch plates cut to such shape that when riveted together they form a bell-shaped section that flares from 17 feet in diameter at the upper end to 27 feet in diameter at the foundation-bolt circle at the base. Vertical anchor bolts hold the chimney to the foundation and prevent it from blowing over. The chimney has a firebrick lining ranging in thickness from 18 inches

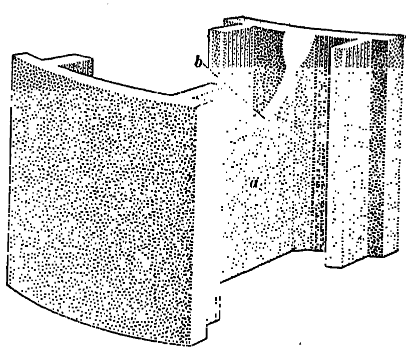


FIG. 18

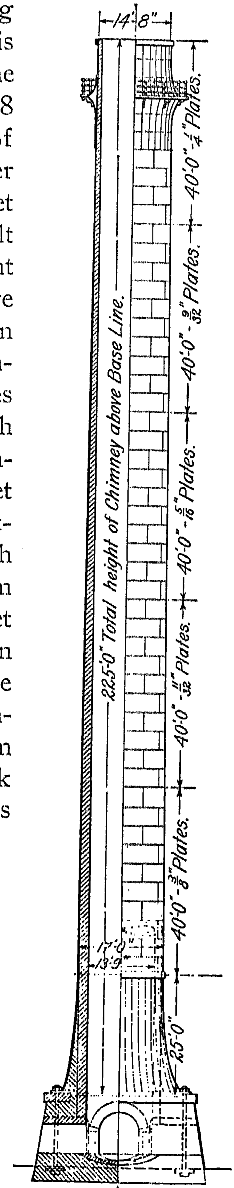


FIG. 19

Outside straps are preferable, as the inside of the stack then has a uniform diameter throughout, with nothing to interfere with the flow of the gases.

29. In the stack construction shown in Fig. 20 (*c*), the sections are tapered, the upper end of each being slightly smaller in diameter than the bottom. The top of each section then fits into the bottom of the section next above, and the

TABLE I

PLATE THICKNESSES AND RIVET DIAMETERS FOR GUYED STACKS

Diameter of Stack Inches	Thickness of Plate Minimum U. S. Standard Gauge	Diameter of Rivet Inch	Thickness of Plate Maximum Inch	Diameter of Rivet Inch
30	10	$\frac{3}{8}$	8 (gauge)	$\frac{3}{8}$
36	10	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{7}{16}$
40	10	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{7}{16}$ or $\frac{1}{2}$
48	8	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{7}{16}$ or $\frac{1}{2}$
54	$\frac{3}{16}$ in.	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{1}{2}$ or $\frac{5}{8}$
60	$\frac{3}{16}$ in.	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{1}{2}$ or $\frac{5}{8}$

two are riveted together. The lap on the outside thus faces down, and so does not form a ledge on which moisture can collect.

The plate thicknesses and diameters of rivets for guyed steel stacks of different diameters are given in Table I. For each diameter a minimum and a maximum plate thickness are suggested with corresponding rivet diameters. If durability and permanence are desired, the thicker plate should be chosen for a given stack. Through the action of flue gases and atmospheric moisture, corrosion is very likely to attack the steel stack unless its surface is protected. It is, therefore, recommended that the stack be painted frequently with a good grade of metal paint.

32. Height of Chimney.—The relation between the height of the chimney and the pressure of the draft, in inches of water, is given by the following rule:

Rule.—*To find the draft pressure of a chimney in inches of water, divide 7.6 by the absolute Fahrenheit temperature of the outside air and divide 7.9 by the absolute Fahrenheit temperature of the chimney gases; subtract the latter quotient from the former and multiply the difference by the height of the chimney, in feet.*

Expressed as a formula, the rule becomes

$$p = H\left(\frac{7.6}{T_a} - \frac{7.9}{T_c}\right)$$

in which p = draft pressure, in inches of water;
H = height of chimney, in feet;
T_a and T_c = absolute temperature of the outside air and of the chimney gases, respectively.

EXAMPLE.—What draft pressure will be produced by a chimney 120 feet high, the temperature of the chimney gases being 600° F., and of the external air 60° F.?

SOLUTION.—By the formula,

$$p = 120\left(\frac{7.6}{460+60} - \frac{7.9}{460+600}\right) = .859 \text{ in.} \quad \text{Ans.}$$

33. To find the height of chimney to give a specified draft pressure, the following rule may be used:

Rule.—*To find the height of a chimney, in feet, divide 7.6 by the absolute Fahrenheit temperature of the outside air, and divide 7.9 by the absolute Fahrenheit temperature of the chimney gases; subtract the latter quotient from the former, and divide the required draft, in inches of water, by the difference of the quotients.*

Expressed as a formula, this rule becomes

$$H = \frac{p}{\left(\frac{7.6}{T_a} - \frac{7.9}{T_c}\right)}$$

EXAMPLE.—Required, the height of the chimney to produce a draft of $1\frac{1}{8}$ inches of water, the temperature of the gases and of the external air being, respectively, 550° and 62°.

EXAMPLE 1.—What should be the diameter of a chimney 100 feet high that furnishes draft for a 600-horsepower boiler?

SOLUTION.—By formula **1**,

$$E=\frac{.3\,P}{\sqrt{H}}=\frac{.3\times600}{\sqrt{100}}=18$$

Now using formula **4**,

$$d=13.54\sqrt{18}+4=61.44 \text{ in. Ans.}$$

EXAMPLE 2.—For what horsepower of boilers will a chimney 64 inches square and 125 feet high furnish draft?

SOLUTION.—By simply referring to Table II, the horsepower is found to be 934. Ans.

35. Maximum Combustion Rate.—The maximum rates of combustion attainable under natural draft are given by the following formulas, which have been deduced from the experiments of Isherwood:

Let F = weight, in pounds, of coal per hour per square foot of grate area;
H = height, in feet, of chimney or stack.

Then, for anthracite burned under the most favorable conditions,

$$F=2\sqrt{H}-1 \qquad (1)$$

and under ordinary conditions,

$$F=1.5\sqrt{H}-1 \qquad (2)$$

For best semianthracite and bituminous coals,

$$F=2.25\sqrt{H} \qquad (3)$$

and for less valuable soft coals,

$$F=3\sqrt{H} \qquad (4)$$

The maximum weight of combustion is thus fixed by the height of the chimney; the minimum rate may be anything less.

The foregoing formulas may also be expressed in the form of a rule, as follows:

Rule.—*To find the maximum weight of coal that can be burned per square foot of grate area per hour, with natural draft: Subtract 1 from twice the square root of the chimney height, in feet, for anthracite burned under the most favorable conditions; subtract 1 from 1.5 times the square root of the*

TABLE II

SIZES OF CHIMNEYS AND HORSEPOWER OF BOILERS

Height of Chimney, in Feet											Effective Area Square Feet	Actual Area Square Feet	Side of Square Inches	Diameter Inches
50	60	70	80	90	100	110	125	150	175	200				
Commercial Horsepower														
23	25	27									.97	1.77	16	18
35	38	41									1.47	2.41	19	21
49	54	58	62								2.08	3.14	22	24
65	72	78	83								2.78	3.98	24	27
84	92	100	107	113							3.58	4.91	27	30
	115	125	133	141							4.47	5.94	30	33
	141	152	163	173	182						5.47	7.07	32	36
		183	196	208	219						6.57	8.30	35	39
		216	231	245	258	271					7.76	9.62	38	42
			311	330	348	365	389				10.44	12.57	43	48
			402	427	449	472	503	551			13.51	15.90	48	54
			505	539	565	593	632	602	748		16.98	19.64	54	60
				658	694	728	776	819	918	981	20.83	23.76	59	66
				792	835	876	934	1,023	1,105	1,181	25.08	28.27	64	72
					995	1,038	1,107	1,212	1,310	1,400	29.73	33.18	70	78
					1,163	1,214	1,294	1,418	1,531	1,637	34.76	38.48	75	84
					1,344	1,415	1,496	1,639	1,770	1,893	40.19	44.18	80	90
					1,537	1,616	1,720	1,876	2,027	2,167	46.01	50.27	86	96

of a pound to the square inch; therefore, draft pressures are not expressed in pounds per square inch, but in inches of water. In other words, the draft pressure is measured by the height of a column of water that will produce a pressure equal to the draft pressure. A column of water 34 feet high and 1 square inch in cross-section weighs 14.7 pounds; that is, the pressure at the foot of such a column is equal to atmospheric pressure. As 34 feet is equivalent to 408 inches, a column of water 1 inch high has a pressure at its base of $14.7 \div 408 = .036$ pound per square inch. Thus, if a draft pressure is said to be $1\frac{1}{4}$ inches of water, the difference of pressure is $1\frac{1}{4} \times .036 = .045$ pound per square inch. The **U** gauge, shown in Fig. 21, may be used to measure draft pressure. As will be seen, it is a glass tube bent to the shape of the letter **U**. The left leg communicates with the chimney, and the right leg at the top is open to the outside air. The air outside the chimney being heavier, it presses on the surface of the water in the right leg and forces some of it up the left leg. The difference in the two water levels h and z in the legs represents the intensity of the draft and is expressed in inches of water.

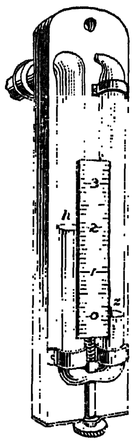


Fig. 21

40. Mechanical Draft.—Under certain conditions it may be out of the question to use natural draft. For example, certain kinds of fuel require very high draft pressure in order to force the necessary amount of air through the fire. The cost of a chimney of sufficient height to supply the required draft may be so great as to make it impracticable to use natural draft. Again, there may not be sufficient room to build a chimney of the desired capacity. In such cases, the draft may be produced by appliances, such as fans, blowers, or steam jets. Draft produced by these means is called mechanical draft to distinguish it from natural draft. It may be either *forced draft* or *induced draft*. With forced draft, the air is forced into the ash-pit under pressure; with induced draft, a partial vacuum is formed at the chimney, and the air and gases are

EQUIPMENT FOR MECHANICAL DRAFT

43. Fans and Steam Jets.—For forcing air under pressure into the ash-pit, either a fan or a steam jet may be used. Steam jets are not favored to any great extent and their use in modern boiler plants is limited. With some fuels, live steam is introduced under the grate to prevent the forming of large clinkers. The steam in passing through the fuel bed is broken up into its two elements, hydrogen and oxygen, and the heat taken from the fuel bed to produce this dissociation cools the lower bed of fuel sufficiently to prevent large clinker formation. It also tends to prevent the grates from overheating. A steam jet has a lower first cost than a fan blower, but the latter is preferable, as it produces better results in the combustion of fuels.

44. A common construction of fans is shown in Fig. 22 (*a*) and (*b*). The shell or housing *a* is made of steel plate,

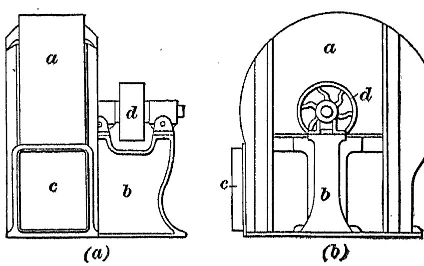


FIG. 22

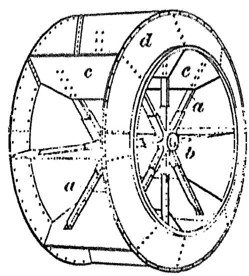
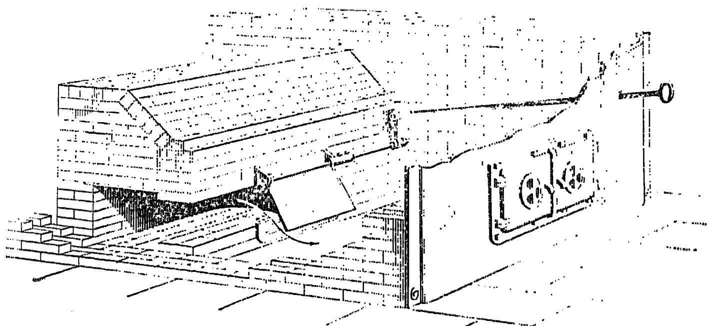


FIG. 23

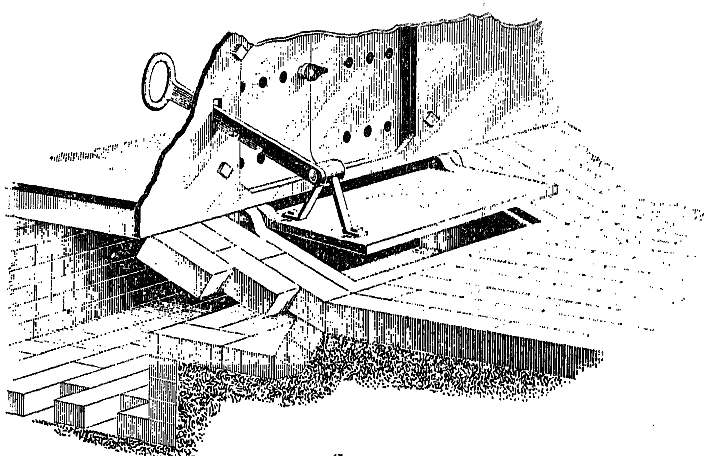
with a substantial base *b* of cast iron or wrought iron. An outlet *c* is placed at the desired point of the circumference, whence the air is discharged into the duct leading to the ash-pit. In the fan shown there is one inlet, which surrounds the fan shaft on the side opposite the pulley *d* through which the fan is driven. The fan shaft is supported in two bearings and carries the fan wheel within the casing. The usual construction of the fan wheel is shown in Fig. 23. Arms *a* made of T iron are fastened to the hub *b* and carry at their ends the blades *c*. These blades are tied together by the side plates *d*.

ashes may readily be raked over it. The damper, when opened, serves to distribute the air thoroughly in the ash-pit.

Concrete air ducts are the most durable, but when low first cost is essential, galvanized iron ducts may be used; in such a



(a)



(b)

FIG. 25

case it is customary to have the main supply overhead and a branch pipe extending down to each boiler.

47. Horsepower Required for Producing Forced Draft. The horsepower necessary to furnish forced draft may be calculated by the following rule:

coal with a fusible ash is used. The number of blowers required depends on the number of boilers, the rate of combustion of fuel, and the capacity of the blower.

49. Induced-Draft Apparatus.—A typical induced-draft installation for a battery of three boilers is shown in Fig. 27. It consists of a single exhaust fan *a* driven by a steam engine *b* directly connected to the fan shaft. For such installations a

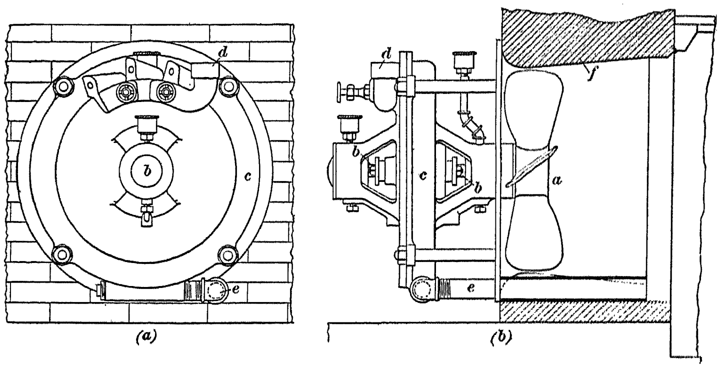


FIG. 26

short stack *c* is directly connected to the fan outlet *d*. A bypass pipe *e* connecting with the breeching *f* and fitted with a damper *g* should always be installed, so as to permit operation with stack draft when starting the fires, when the plant is operating under a light load, or when repairs are required to the fan or the engine. By using induced draft with hand-fired furnaces an increase of boiler capacity up to 200 per cent. of rating may be obtained; and an increase of capacity up to 400 per cent. of rating can be obtained by using forced draft in combination with induced draft. The intensity of draft may be regulated either by hand or by some form of automatic control.

DRAFT CONTROL

50. Balanced Draft.—A system of combined forced draft and induced draft has been worked out, in which the fuel feed, the air supply, and the stack draft are all automatically con-

trolled by an interlocking regulation, so that the combustion conditions are always suited to the condition of the fire. The arrangement of the various regulating devices used in this system is shown in Fig. 28. A fan *a* driven by a steam tur-

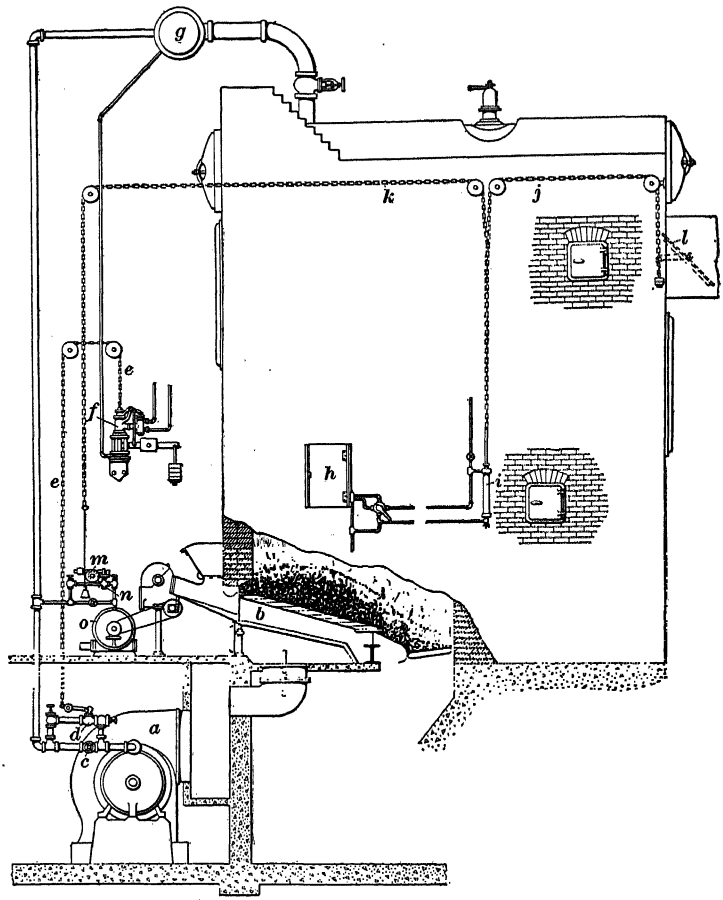


FIG. 28

bine supplies air under pressure beneath the grates *b* and thus enables the air to overcome the resistance due to the thickness of the fuel bed. The minimum speed of the turbine driving the fan is fixed by the amount of opening of the valve *c* in the

flexible diaphragm dividing the chamber into two parts. The under part is filled with water subjected to the boiler pressure through the steam pipe *d*. The diaphragm tends to move upwards under the influence of the steam pressure, but its upward motion is resisted by the downward force exerted by the weighted lever *c*. The weights are so adjusted that the lever will occupy a position midway between its two extreme

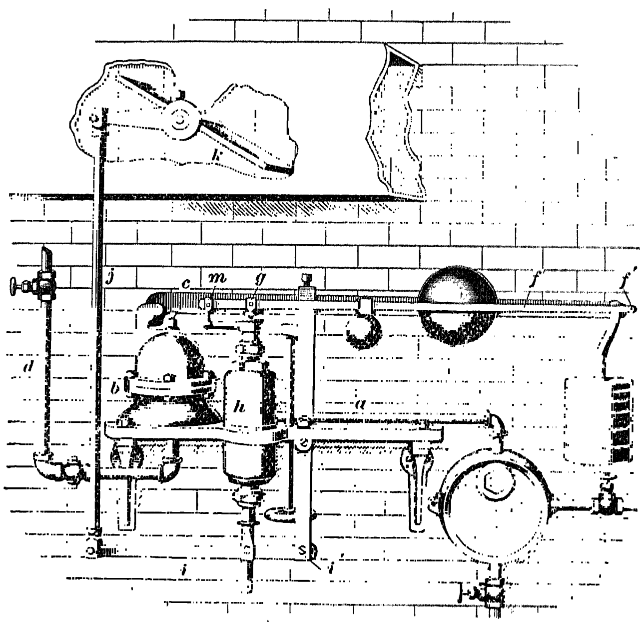


FIG. 29

positions when the steam pressure in the boiler is exactly at the point at which it is to be carried. A secondary lever *f* is hinged at *f′* to the free end of the lever *c*. The secondary lever is fulcrumed at *m*, and at *g* the valve stem of the operating valve is attached to it. This valve works inside a piston that is closely fitted to the stationary cylinder *h*, the valve serving to admit water under pressure to either side of the piston. The piston rod passes through both heads of the cylinder *h*; at its lower extremity it is connected to the lever *i* pivoted at *i′*,

54. The cylinder *h*, Fig. 29, is shown in section in Fig. 30. The piston is made water-tight by the cup leather packing rings *r*. The water under pressure enters through the supply pipe *a* and surrounds the piston, entering through a small port into the central valve chamber and then surrounding the central part of the piston valve *t*. When the valve moves upwards

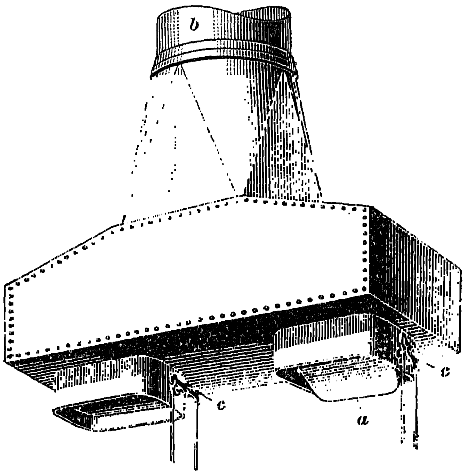


FIG. 31

it uncovers the ports *e′* and *e*; the water under pressure flows through the port *e′* into the lower part of the cylinder; at the same time the water in the upper parts flow through the port *e* into the hollow piston rods *s* and out at *l*. The resultant motion of the piston then returns the valve to the central position shown. If the valve descends, it admits the water into the port *e* and allows the water in the lower half of the cylinder to escape through the port *e′* into the passage *s′*, which, through a by-pass port not shown, communicates with the passage *s*. The descent of the piston again returns the valve to its central position.

55. Hand-Operated Draft Regulator.—In Fig. 31 is shown a breeching with hand-operated dampers, as used in some power plants. The damper consists of a plate *a*, which may be placed in either the uptakes or in the stack *b*. The plate is fastened to the damper rod, and is opened or closed by

lever *d* that is fastened to the piston rod *e* of a piston that fits inside the dash-pot *f*. The lever *d* is connected by a crank to the shaft *g*, which in turn is connected to the fire-door by a rod *h* and a crank. The fireman in opening the fire-door causes the shaft *g* to turn, which in turn operates the lever *d* and thus opens the valve *b*, allowing steam to enter through

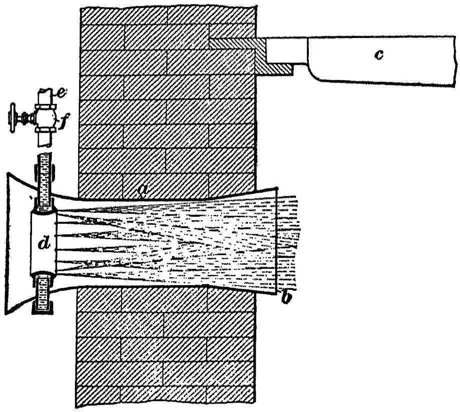


FIG. 33

the jets *c*. The air door *i* is also opened at the same time by the turning of the shaft *g*, which carries a dog *j* that presses against the lever *k*. Steam and air are admitted for some time after the fire-door is closed; but during this period the dash-pot piston automatically descends, gradually moving the lever *d*, turning the shaft *g*, and thus closing the valve *b* and the air door *i*. The advantage of this device is that the gases and the air are intimately mixed during the period in which the volatile matter is being driven off from the fresh fuel, thus preventing smoke and saving fuel.

57. Argand Blower.—The Argand blower, shown in Fig. 33, is a device for producing a supply of air under pressure in the ash-pit and is operated by steam jets. It consists of a long air tube flared at both ends and inserted through the front wall of the setting, so that the inner end *b* is beneath the forward end of the grates *c*. At the outer end is a hollow

Another method of accomplishing the same result is shown in Fig. 35. In this case the blower consists of a short piece of pipe *a* closed at the ends and perforated along its top, steam

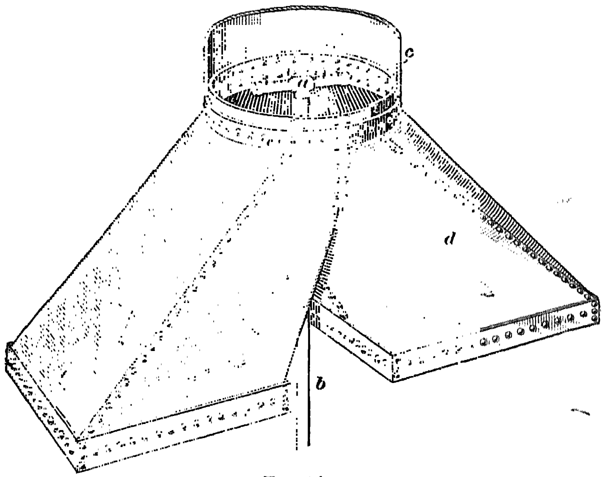


FIG. 35

being supplied through the pipe *b*. The blower is placed at the base of the stack *c*, where it joins the **Y** breeching *d*. Instead of a straight pipe *a*, a ring may be used.